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* NATIONAL RESEARCH COUNCIL CANADA *
* INDUSTRIAL MATERIALS RESEARCH INSTITUTE *
*
* SELECTED APPLICATIONS *
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* FOR *
* PROFESSIONAL DEVELOPMENT PROGRAMME *
* ON *
* COMPUTER INTEGRATED INJECTION MOULDING *
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1 INTRODUCTION

The progress of injection moulding techniques leads to the development of larger and more complicated mouldings. The quality specifications increase constantly, as well as the designer's responsibilities for costs, because of larger, more expensive moulds, high-grade injection moulding machines with a high hourly cost and custom materials processing. As a consequence, a comprehensive analysis of the process is required at an early stage of the design phase.

Since the single parameters are all inter-dependent, the determination of flow, pressure and temperature conditions is so complicated that the solution of these equations is impossible with conventional methods. Thus the solution of complicated models requires the use of computer systems.

The analysis of the process and the lay-out on the mould are based on simulation models and mathematical laws describing the flow process. The programs are user friendly, and interactive. Flags are installed that tell the user if the processing conditions are outside of the limit for the material. This speeds up considerably the design of the moulded part.

The calculation of injection moulds leads to a program system with the following design areas:

- rheological
- thermal
- mechanical

-The material data base makes the required material data available to the simulation programs. Since thermoplastics properties vary with temperature, pressure, etc, constant or variable properties can be installed in the data-base and transferred to the programs as required. Mathematical models can be choosen to represent the variation of the property.

The programs themselves are subdivided into various modules which can be used for specific purposes. The three main choices are:

-Injection simulation

-Design and analysis of the cooling system of the mould.

-Calculation of the deformation of the mould and press during the injection process.

In this system, the fundamentals, the simulation programs and the handling of the results are connected in a way as to enable the user to realize a complete rheological moulding analysis and mould lay-out.

2 PRELIMINARY ADVICE

It must be stressed that the use of such advanced Computer assisted design systems is not a substitute for Know-how and experience. These programs will provide a considerable increase in productivity and flexibility of design, and manufacturing but the analysis of the

results and the choices to be made must still be made by the user. Wrong choices will lead to faulty designs. Further, any such programs have their advantages and limitations. A good knowledge of these limitations which will come after some use, will spare the user some surprises. These advantages and limitations will be presented to the reader in this manual.

CHAPTER 1

APPLICATIONS AND SUPPORTING DATABASES

1.1 DATABASE

There is a definite relation between what is available in a data base and the main steps in the development of a given product. An integrated approach will include such applications as selection of materials, preliminary design of the mould and various analyzes to optimize the product. The advantages of such an approach are numerous: Centralization of information, rationalization of the design, compatibility of information between different modules.

This system includes a general database that is accessible to all of the analysis programs. The main types of materials necessary for the simulations are resins, metals and cooling liquids. However, any type of material or property can be entered by the user and accessed by other programs.

1.2 CONSTANT AND VARIABLE PROPERTIES

The properties of most materials are considered constant. This is not true for plastics: Properties of plastics vary with temperature, pressure, etc. It is therefore necessary to be able to store constant and variable properties. This is done by having a number of behavior laws available as equations, with the coefficients stored in the data base.

Table 1 presents a list of the variable properties presently installed in the program.

** L I S T O F V A R Y I N G P R O P E R T I E S **

PROPERTY	UNIT	GRAMM.	FILE-NO.
PROPERTY NO. 1-6 NOT YET INSTALLED			1 - 6
DENSITY	[KG/M**3]	RHO	7
SPECIFIC HEAT CAPACITY	[J/KG*K]	CP	8
THERMAL CONDUCTIVITY	[W/M*K]	LAMBDA	9
THERMAL DIFFUSIVITY	[M**2/S]	A	10
SPECIFIC ENTHALPY	[J/CM**3]	ENTH	11
REAL THERMAL DIFFUSIVITY	[M**2/S]	AEFF	12
VISCOSITY	[PA*S]	ETA	13
TEMPERATURE SHIFT		T	14
MODULUS OF ELASTICITY	[PA]	ELAM	15
KINEMATIC VISCOSITY	[M**2/S]	NUE	16
PRANDTL-NUMBER		PR	17
PRESSURE SHIFT FACTOR	[DEG C/BAR]	FP	18
PROPERTY NO. 19-42 NOT YET INSTALLED			19 - 38

Table 1: List of variable properties.

1.3 TYPES OF PROPERTIES

Properties are grouped according to the following types:

1. Rheological properties are the basis of the analysis of the filling phase and the balancing programs. They describe the behavior of the material during the injection phase.

2. Mechanical properties are necessary for the mechnical analysis of the mould and mould plates. They describe the resistance of plastics as well.

3. Thermal and thermodynamical properties describe the behavior of the material with regard to temperature. They are used by the filling phase simulation and the cooling analysis.

4. Processing limitations explain under what conditions the material must be injected, what the settings of the injection press should be and what the limit conditions for processing are. These properties are the basis of an expert system which will assist the user in the choice of a resin for a given application and in the design of the cavity and runners.

CHAPTER 2

MODELLING OF FEEDING SYSTEMS

2.1 INTRODUCTION

The design and dimensioning of feeding systems are considered to be an important task in the design stage of in jection mould. Also, the feeding system design can determine part quality and cost as well as the amount of waste and regrind material.

Using an interactive software package based on solid modeling for the design of feeding systems can have many advantages. Such a user friendly software can be an added value to other application software such as the flow and cooling analyses, mould and cost estimation, and tool path generation. A parametric data base has been developed for the most common feeding system configurations by taking into account the design and manufacturing guidelines material characteristics, and polymer processing parameters.

Over the past few years, work has progressed toward the acceptance of solid modeling technology, which represents the key to computer integrated injection moulding. Presently, the design step of the feeding system involves sketching alternative concepts or paging through reference books and moulding manuals or personal notes. This software goes beyond the geometric construction of the feeding system, and provides the bridge to link the design step to other applications and improve the total manufacturing process of injection moulds. Key factors such as end user requirements, modularity and reliable information are at the core of this development. Today, mould designers are under pressure to make the right decision soon enough so as not to hold up other design or planning operations.

The software consists of a parametric data base with an advanced user interface that supports the construction of a wide variety of runner and gate configurations.

2.2 DEVELOPMENT AND FEATURES:

The concept is to provide the mould designer with a library of special functions from which he can meet his application requirements.

The development of "PLASFEED" involved the acquisition, correlation and synthesis of graphics and alphanumeric information. It was developed on Applicon's Bravo! solid modeler to operate in computer aided engineering environment.

The software has a variety of extended features which add the functionality and performance needed for the production of injection moulds. The user interface is simplified with an on-screen menu and on line documentation. Also, this knowledge-based software consists of a set of graphics support subroutines for faster and more efficient design process. It captures the most common design practices and guidelines for different moulding materials.

PLASFEED was designed with the end user requirements in mind, it features:

- Inherent design methodology and flexibility
- Direct access to material dependent design parameters
- A standard set of design primitives for runners and gates
- Internal diagnostics to help quickly isolate potential design problems.

2.3 INTERACTIVE SOLID MODELING OF RUNNERS AND GATES:

The first module consists of eight primitives in a natural format to support the design of runners. The menu shown in figure 1 is intended for an automatic selection and display of these primitives . Primitives can be connected together at any time to construct the complete runner system. This module is highly versatile and can support round and trapezoidal runner cross sections. Another possibility is to diagnose existing design alternatives for evaluation and correction. Once the preferred design is selected, the geometric construction involves specifying the exact dimensions of these primitives. Typical examples are shown in figures 2 and 3 for H and S shapes respectively.

The second module lets the designer rapidly create the gating system. Once the appropriate gate is selected from the main menu, see figure 3 for illustration, the designer should input the design parameters. Typical examples are shown in figures 4 and 5 for a submarine and pinpoint gate respectively. This can be done through an on line access to reference documentation as illustrated in table 1. The user can interactively select the resin to be moulded and input these design parameters which are material dependent. Design modifications are possible since the system can automatically update the model.

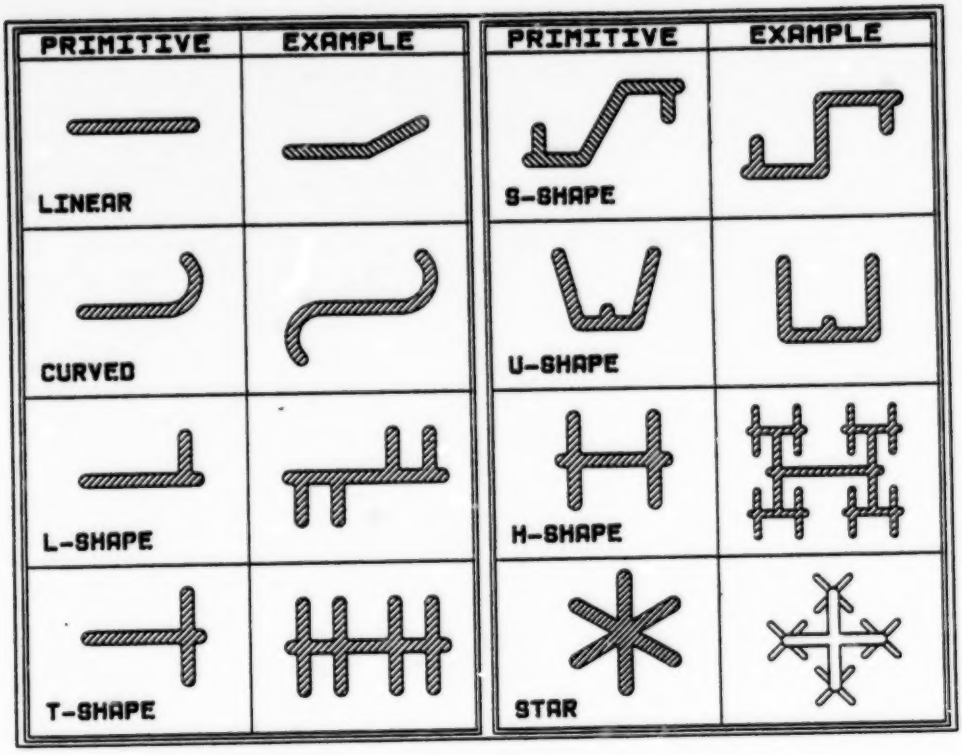

FIGURE 1: Graphic menu for the design of runners

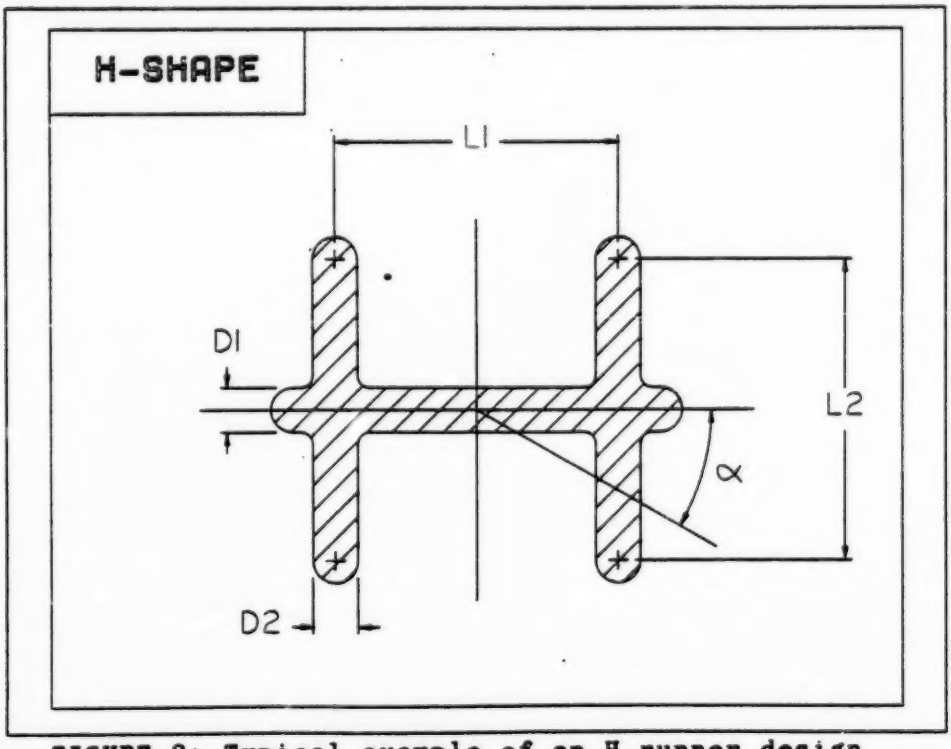

FIGURE 2: Typical example of an H runner design

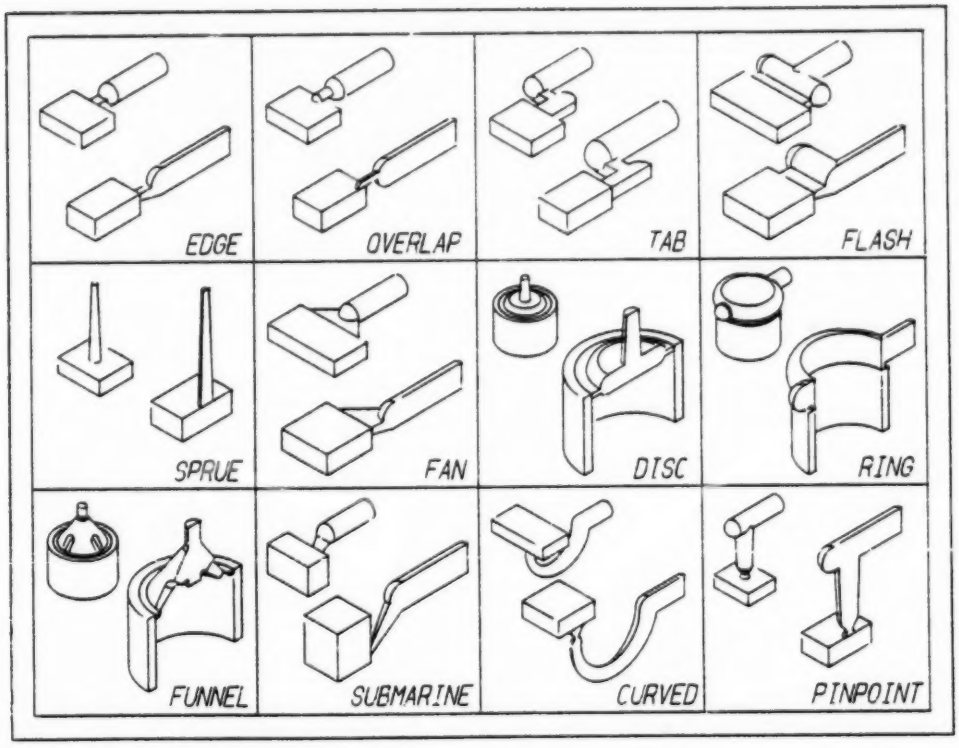

FIGURE 3: Graphic menu for the design of gates

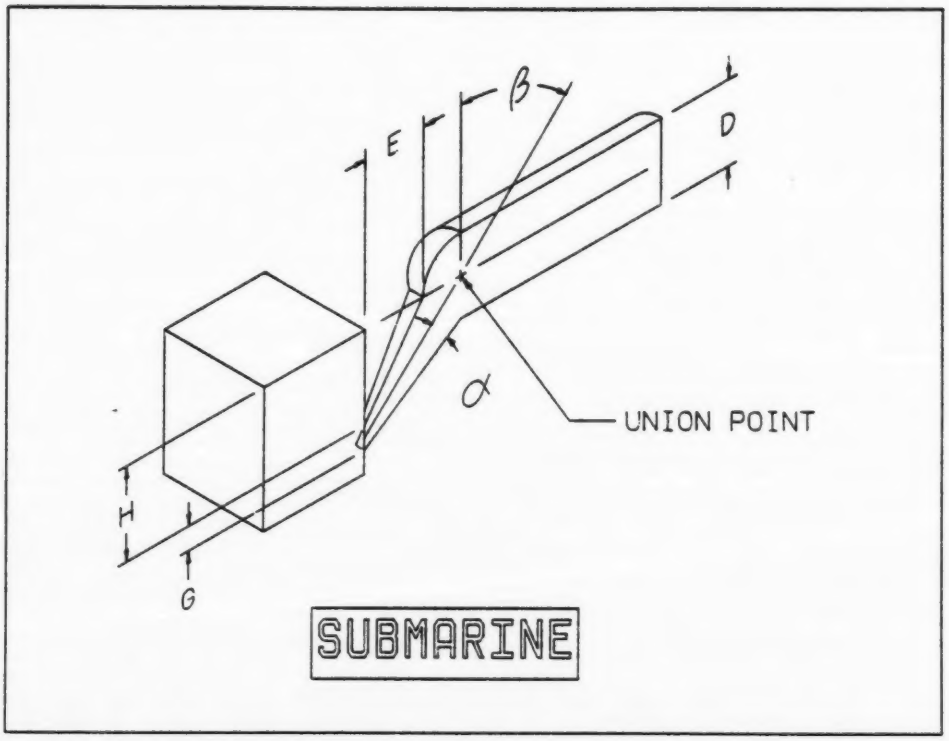

FIGURE 4: Typical example of a submarine gating system

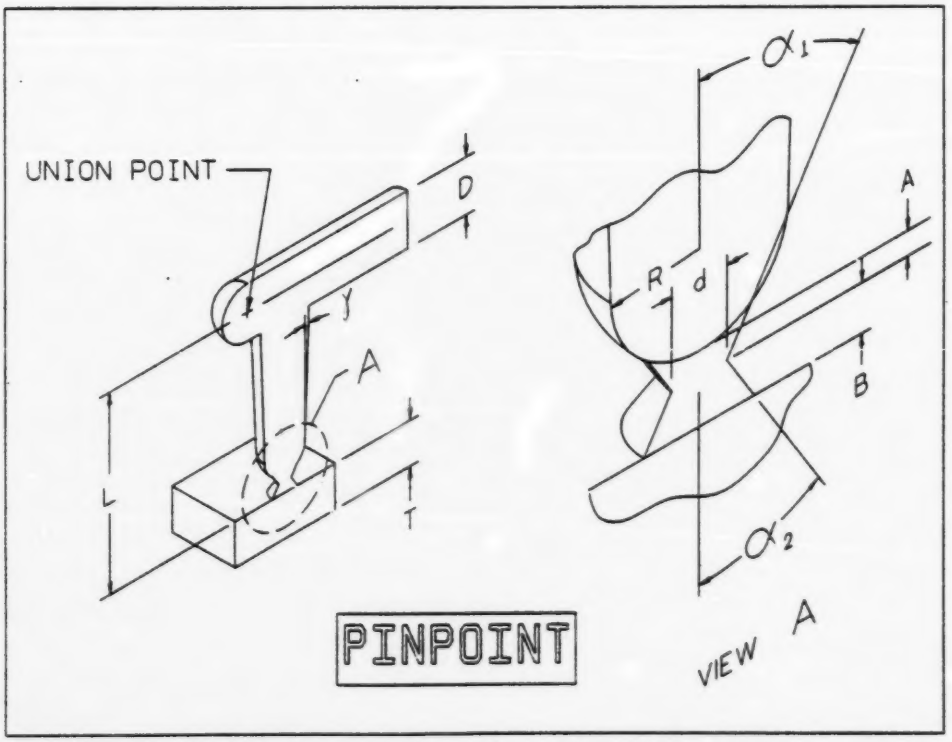

FIGURE 5: Typical example of a pinpoint gating system

EDGE GATE

MATERIAL	T	H	W	L	N
ABS	<= 2.4mm	1.6 - 2.4mm	2.4 - 3.2mm	<= 1.0mm	0.7
	2.4 - 3.2mm	2.4 - 3.2mm	3.2 - 6.4mm	<= 1.0mm	0.7
	3.2 - 4.0mm	3.2 - 4.0mm	6.4 -13.0mm	<= 1.0mm	0.7
ACETAL	<= 3.0mm	<= 1.5mm	<= 1.0mm	<= 1.0mm	0.7
NYLON	<= 0.8mm	<= 0.8mm	<= 1.1mm	0.8 - 1.3mm	0.5
	0.8 - 3.0mm	1.3 - 2.0mm	1.3 - 2.0mm	0.8 - 1.3mm	0.5
	3.0 - 6.0mm	1.5 - 3.6mm	1.5 - 3.6mm	0.8 - 1.3mm	0.5
POLYESTER PBT	<= 0.8mm	<= 0.4mm	<= 0.5mm	0.5mm	0.7
	0.8 - 2.5mm	0.4 - 1.0mm	0.8 - 2.5mm	0.5mm	0.7
	2.5 - 3.0mm	1.0 - 1.5mm	2.5 - 3.0mm	0.5 - 0.8mm	0.7
	3.0 - 6.0mm	1.5 - 3.0mm	3.0 - 6.0mm	0.8 - 1.5mm	0.7
PP	<= 6.0mm	0.5 - 3.0mm	0.5 -25.0mm	<= 1.0mm	0.7
PPO	<= 1.5mm	<= 1.5mm	<= 3.0mm	0.5 - 1.0mm	0.9
	1.5 - 6.5mm	1.5 - 3.2mm	3.0 - 6.3mm	0.5 - 1.0mm	0.9

TABLE 1: Dimensionning table

As a result, this family of gates provide the mould designers with more opportunities to quickly construct and evaluate the most suitable gating system for the application requirements. These options extend the basic capability of the designer by providing better support, repeatability and consistancy.

2.4 TYPICAL APPLICATIONS TO THE DESIGN OF FEEDING SYSTEMS:

The software has been sucessfully applied to many configurations of feeding systems. The distributed architecture permits the designer to select, combine and modify the design primitives. As such, the solid modeler provides commands to copy, scale or mirror the model. As illustrated, in figures 6 and 7, the primitive can be merged together to construct the complete feeding system. The same geometry can then be segmented for the melt flow analysis or flow balancing in a family mould. Also the solid model of the feeding system can be substracted from the cavity plate to obtain the negative, as shown in figure 8 and 9.

The approximate model already generated during the construction of the feeding system can be processed for the calculations of mass properties and the boundary file (exact 3D mathematical representation of the solid model). Furthermore, this information may be used as a basis for the calculation of regrind, shot size and cost estimation or CNC tool path generation.

Therefore, many design alternatives can be evaluated to ensure that the selected feeding system will meet all operational objectives including shape, size, weight and cost. The technical documentation is usually available from the solid modeler. In addition, the solid modeler allows the designer to examine the fecting system from different angles. The model may be viewed in section with hidden line removed or as shaded image on the raster screen. The designer should also be able to modify the geometry to reflect any changes that might occur as a result of these calculations.

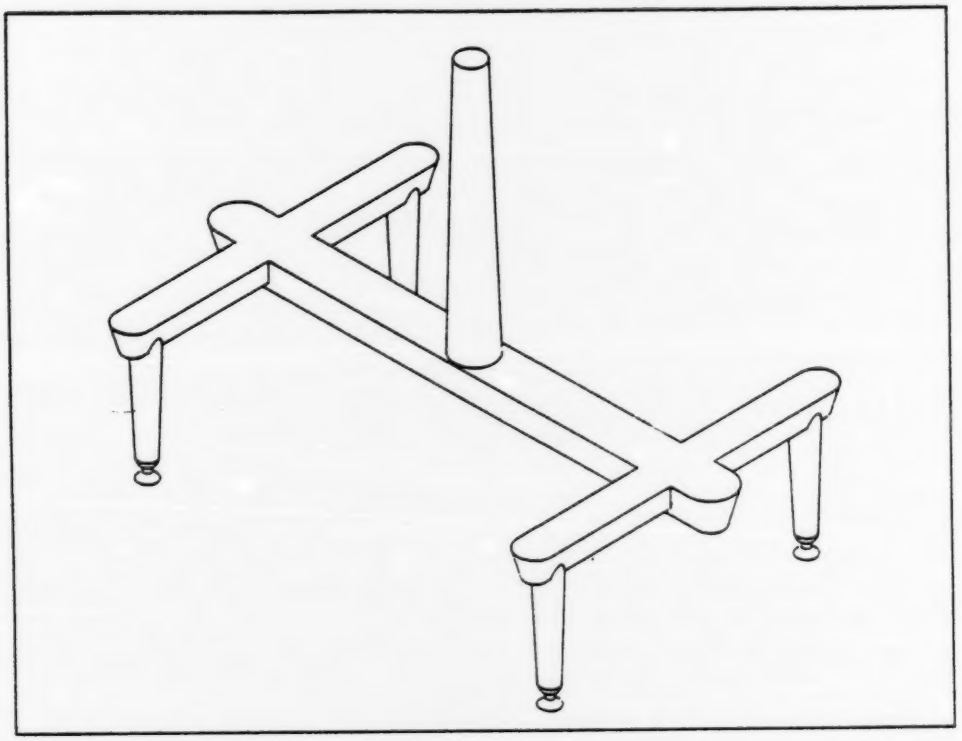

FIGURE 6: Application to the design of a complete feeding system for a three plate mould.

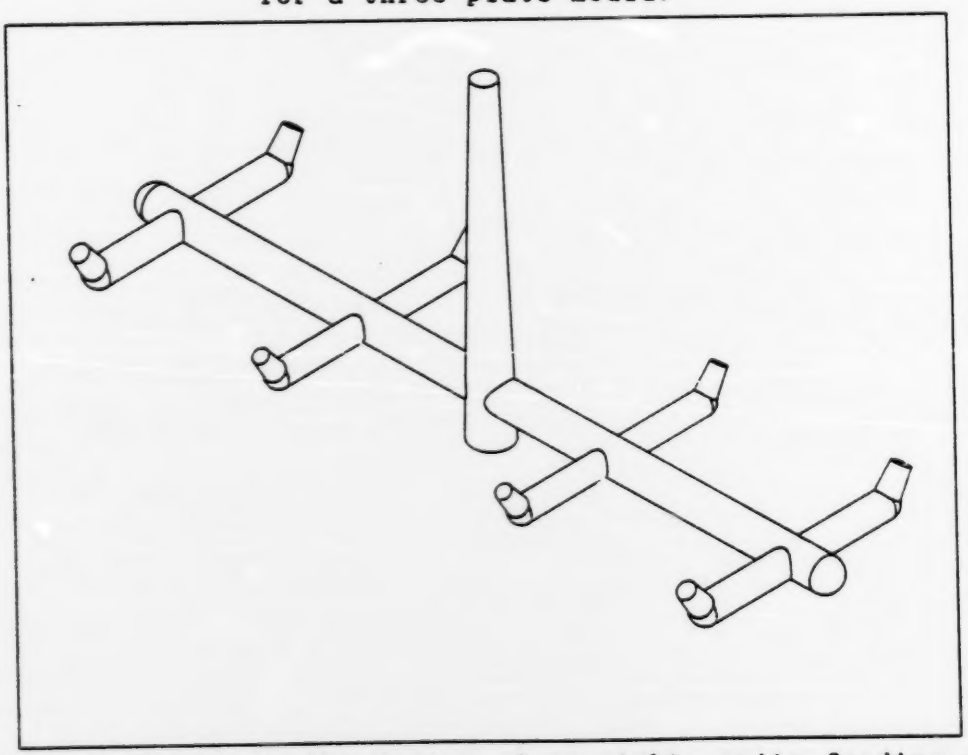

FIGURE 7: Application to the design of an eight cavity feeding system

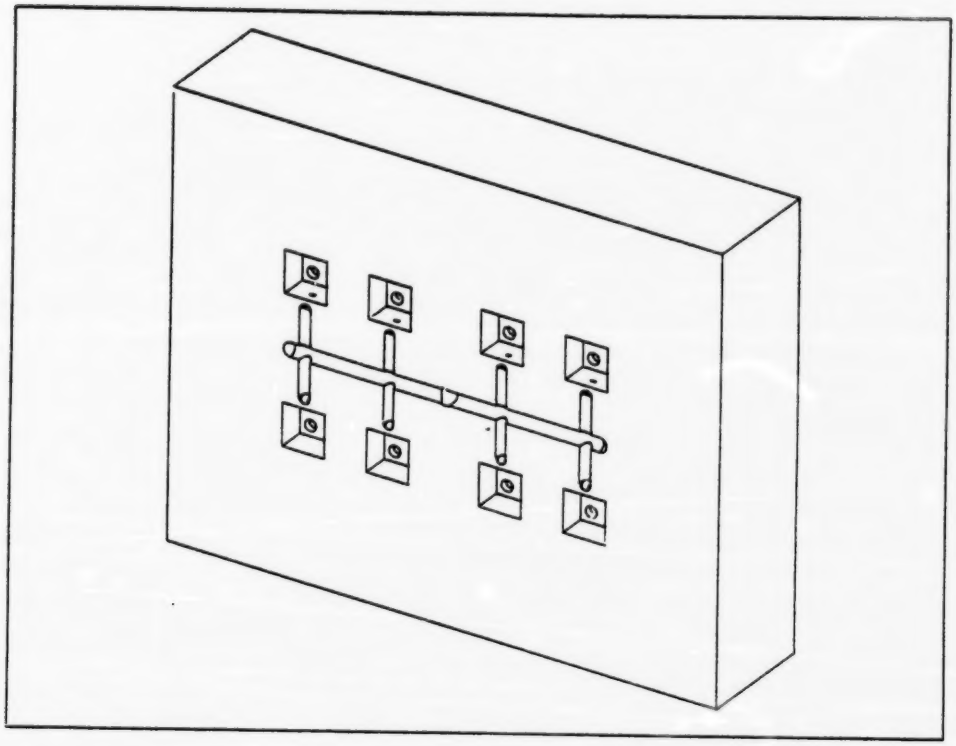

FIGURE 8: Cavity plate as obtained by solid modelling

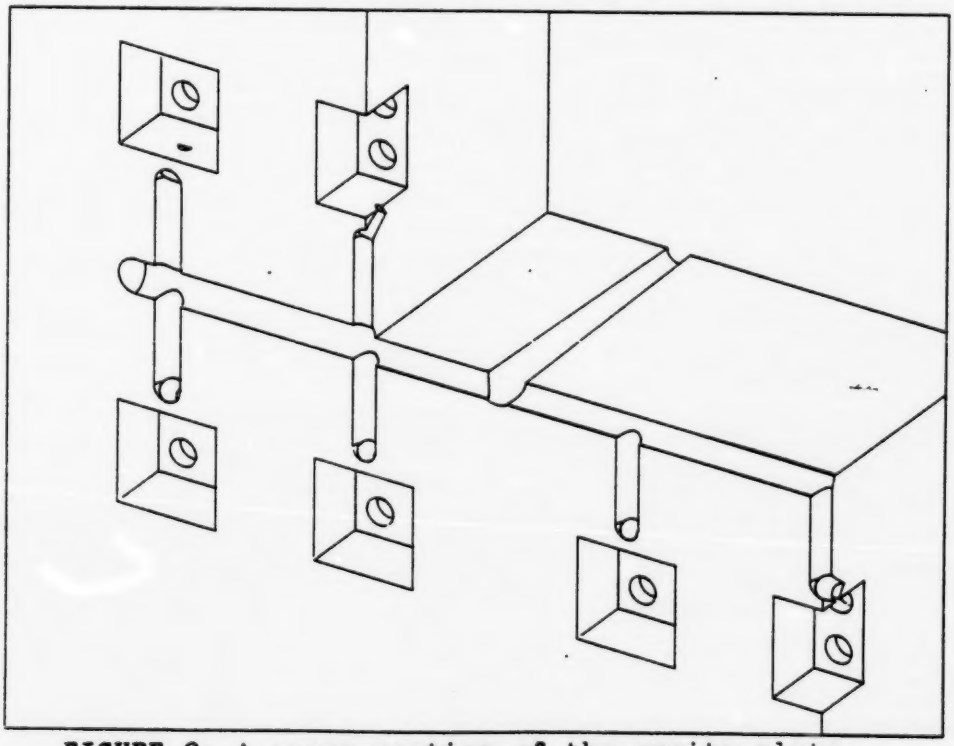

FIGURE 9: A cross section of the cavity plate

CHAPTER 3

MOULD FILLING ANALYSIS

3.1 SIMULATION OF THE FILLING PHASE

Examples are presented for the specific program being run. The methods used to generate the flat pattern of the part and the different flowpaths are explained. Parameters and input values are listed and described to enable a new user, without any previous knowledge, to use the system.

The lay-out possibilities and particularly the evaluation of the numerical results is discussed. The interpretation of the results is very important. The user has to decide whether the calculated results from the simulation are feasible or if they are outside of process limits. Some flags are available to assist the user; for example, the minimum flow temperature and maximum shear stress are checked during the simulation and the user is flaged if the calculated values exceed the specified material limits. (1)

The simulation of the filling process calculates the values for injection pressure, filling time, melt and wall temperature. These values can then be used as input values for the mechanical and thermal analyses. The primary variable for the filling process in injection moulds is the injection pressure. It determines the mechanical demands on the mould, as well as the capacity required for the injection moulding machine.

Consequently the rheological analysis of the filling process is described with special regards to the actual injection pressures.

3.1.1 Description Of The Primitive Geometries Used By The Program

There are three types of primitive geometries, each with its own type of flow, used by the program. Each type has its own properties and will give different results.

3.1.1.1 Flow In A Disk Shape -

The circular disc (Fig. 10)is the basic geometry which allows pronounced swell flow, such as occurs after gates or gate-like joints.

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(1) The properties used to flag the user must be present in the data-base for the material used.

3.1.1.2 Flow In A Plate -

Laminar flow of viscous molten materials (Fig. 11) can be found in a plate with a fan gate (Fig. 12).

It is also to be found in cavities with edge gates or tab gates after long flow distances.

3.1.1.3 Flow In A Cylinder -

The flow of molten material through a cylinder leads to another primitive geometry. Cylindrical flow (Fig. 13), together with cylindrical parts or sections of parts which can be described as cylinders, are of particular interest in the calculation related to gates.

3.2 BASICS OF THE FLOW PATTERN GENERATING METHOD

The physical principle of the flow pattern method is primarily a calculation of the pressure requirements. The application of the balancing equations for flow processes (continuity, impulse and energy equations) leads to a relationship for the pressure requirements.

If one considers the filling process starting at the gate, an increase in pressure P1 is equally effective in all directions and causes the forward flow of the material.

For a plate as shown in Fig. 14, this means that the pressure losses in the two directions with different wall thicknesses can be regarded as equal.

$$P1 = P2$$

If one assumes that the same temperatures occur inside both walls (isothermal flow), then the material behaves in the same way in both cases.

It can then be shown that the flow behaves according to the following law:

$$L1/H1 = L2/H2 \qquad (1)$$

this result, the filling process is determined entirely by the geometry, i.e. by the thickness of the part. The flow behaviour of the molten material is of no importance in this consideration.

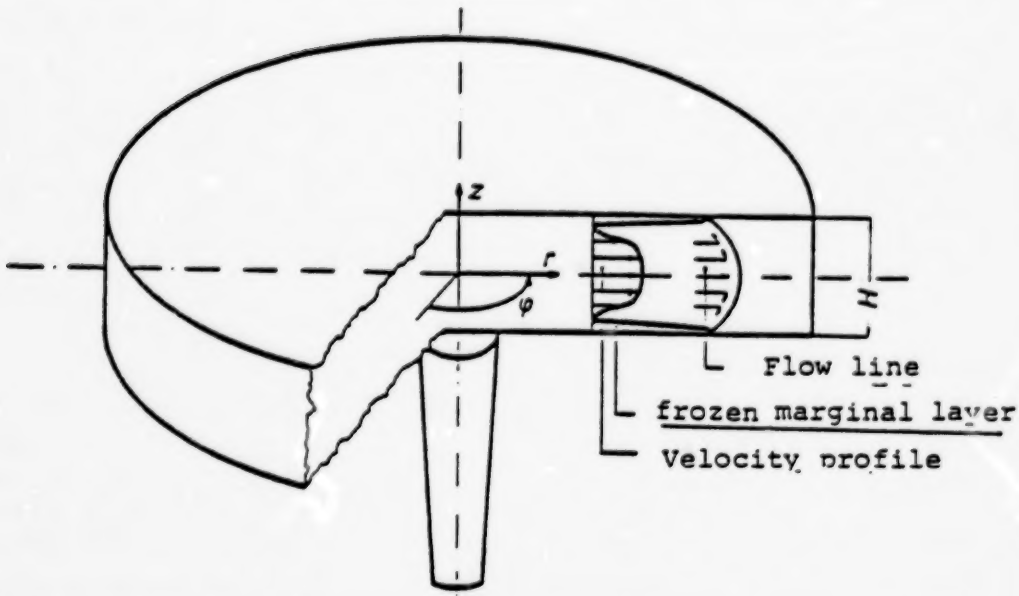


FIGURE 10: Flow for a circular disk (swell flow)

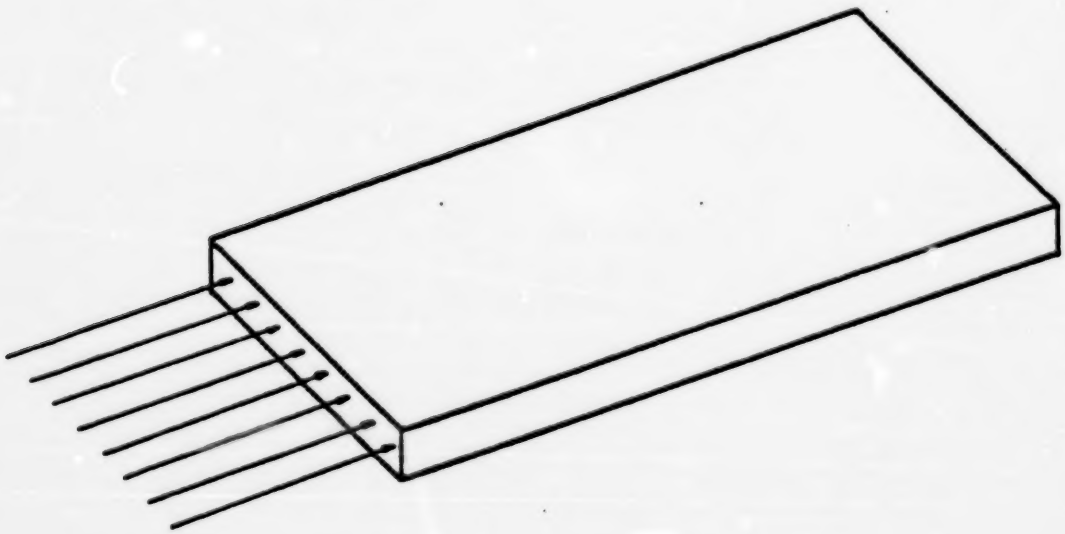


FIGURE 11: Flow for a plate (laminar flow)

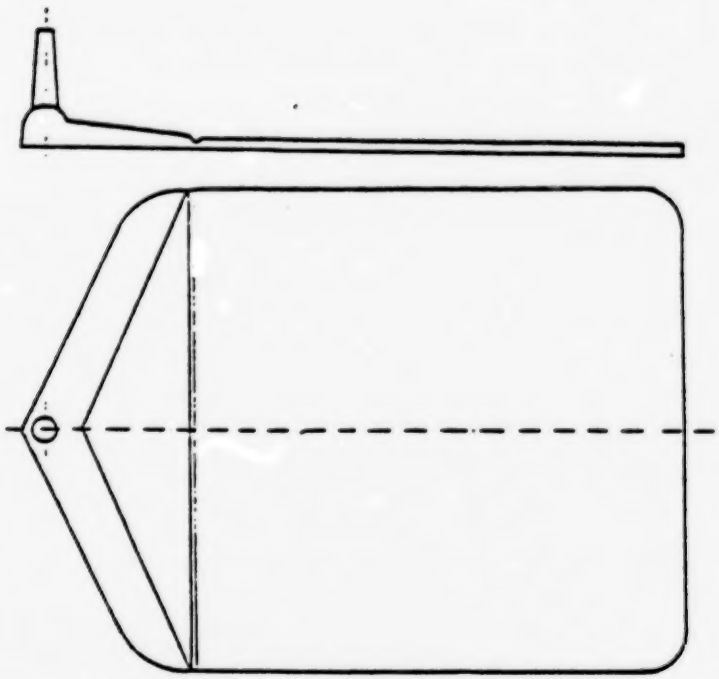


FIGURE 12: Plate with a fan gate.

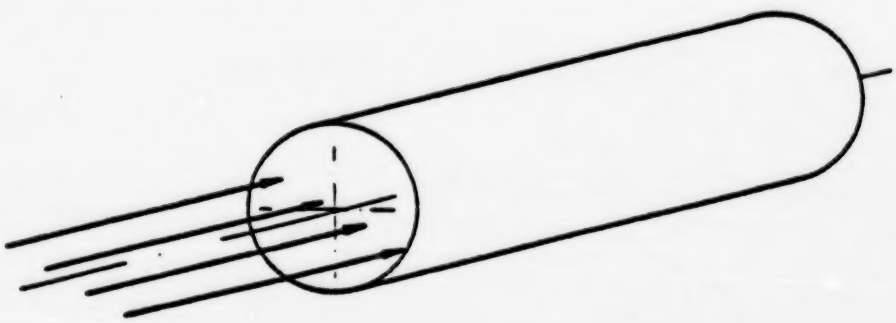


FIGURE 13: Cylindrical flow

3.2.1 Construction Of The Flow Pattern: Generalities

The simple relationship presented in equation (1) allows the position of the flow front to be determined at various points of time. Several examples of increasing complexity will be presented to illustrate the method. The first example is the plate with the direct sprue.

3.2.2 Plate With A Constant Thickness

The gate is always the starting point for the construction of the flow pattern. (fig 15). The melt spreads out from the gate with a given circular radius (1 cm for example) in a time interval t. Since the generation of the flow pattern is based on the part's geometrical dimensions only, the time interval is not determined at this stage. During the calculations, the program will calculate the values for the filling times.

The value of the step length should be choosen according to the part geometry. For simple parts, values in the centimetre range are satisfactory. For more complicated parts, the interval must lie in the millimetre range in order to adequately describe the flow of the melt over small areas and at critical points.

Following these rules, the flow pattern of the filling of the mould can be drawn easily. The maximum number of elements in the mould is limited by the system to a total of 600. This means, for example, 30 flow paths with 20 elements per paths. However, new versions can be generated to use a higher number of elements.

A few supplementary considerations are necessary to carry out a rheological calculation and interpretation based on the flow pattern.

3.2.3 Combination Of Basic Primitive Geometries To Describe Complicated Parts

Two further steps must be taken in order to carry out rheological calculations of parts which cannot be clearly assigned to any one of the basic primitive geometries.

In the simplest cases, for example, a simple plate, the filling process can be described with a single flow path. However, real parts, with many gates and complicated geometries, lead to a large number of different flow paths.

The program requires a description of the movement of the flow fronts over these flow paths, using the basic geometries. The calculation of basic geometries can then be carried out.

For the combined calculation, the end results from one element of the flow path are used as input values for the following element. The minimum number of elements should always be used to describe a complicated geometry. It is usually feasible to connect several flow-path fronts with the same geometry together, to form one basic

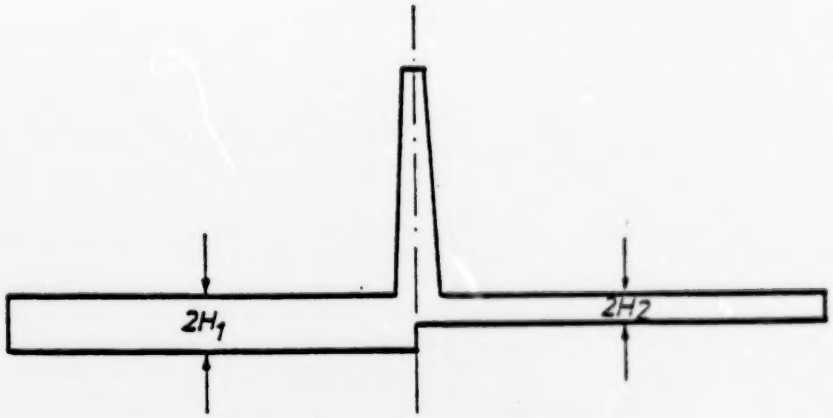


FIGURE 14: Plate with two wall thicknesses

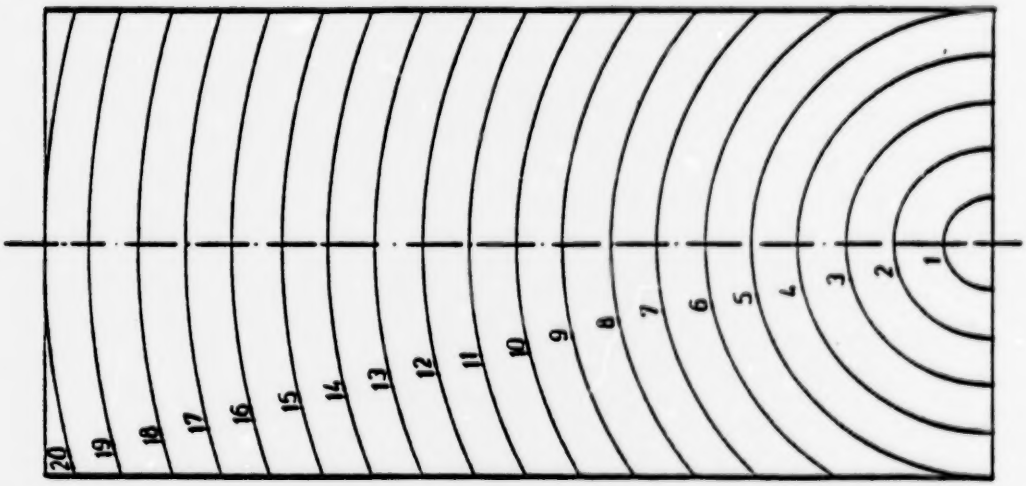


FIGURE 15: Flow pattern of a plate with direct sprue

geometry.

For the flow pattern in Fig. 15, this means collecting together the flow steps 1 to 5 into a disc segment with an outer radius of L = 2.5 cm and a segment angle of 180 degrees. All of the following flow fronts are described by disk shaped geometries.

3.2.4 Plate With Varying Wall Thicknesses

Although changes in wall thickness should be avoided in injection moulded parts to ensure minimum internal stress and an economical cycle time, this is not always attainable in practice. Wall thickness changes are important in the rheological analysis of the filling process. The wall thickness determines the flow resistance and thus the pressure loss.

Fig. 16 shows a plate moulding with wall thicknesses of 2mm (big area) and 1mm (small area).

3.2.5 Flow Pattern With Varying Part Thickness

The flow pattern method can simulate changes in part thickness in mouldings.

The flow path steps must be compatible with the choosen alculation methods. The program assumes that all elements at a given flow path step will be filled at the same time. Once you choose the step for the reference flow path, the steps in the other flow paths must be determined so as to insure the simultaneous filling of all flow paths and elements. This can be achieved by the use of equation (1).

First, draw the flow pattern for the main flow path, using a constant step. This flow path will be used as a reference for the other flow paths. Starting at the sprue MO, the filling diagram for the section with a wall thickness of 2 mm is constructed (Fig. 17.). The flow lines drawn in this manner are stopped at the edge of the 1 mm thick section of the cavity. Note that point C on the boundary A-Y is determined in this step.

The melt enters the 1 mm thick section at point A of the flow front No. 10 (Fig. 17). Since the melt flows according to wave theory law, every point on a flow front can be regarded as the origin of a new centrally propagating flow front. Point A of the 10th flow front is the origin of a new flow front in the 1mm area.

The radius of the flow front in the 1mm area, being propagated in a circle about A, is determined by a wall thickness constant Kt defined as:

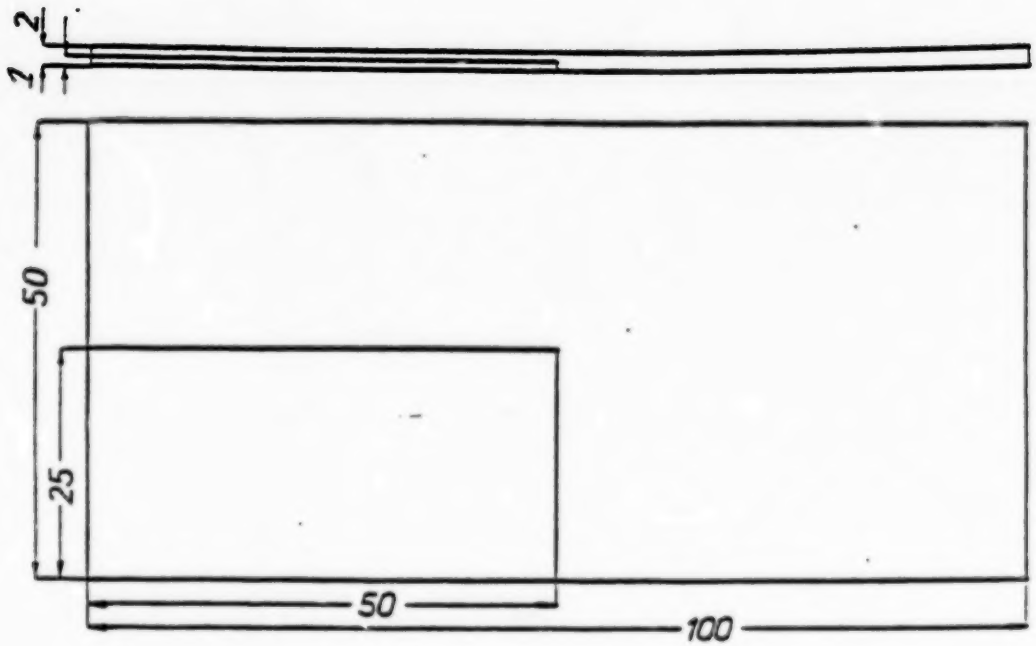


FIGURE 16: Plate with a variation of thickness: 2mm and 1mm.

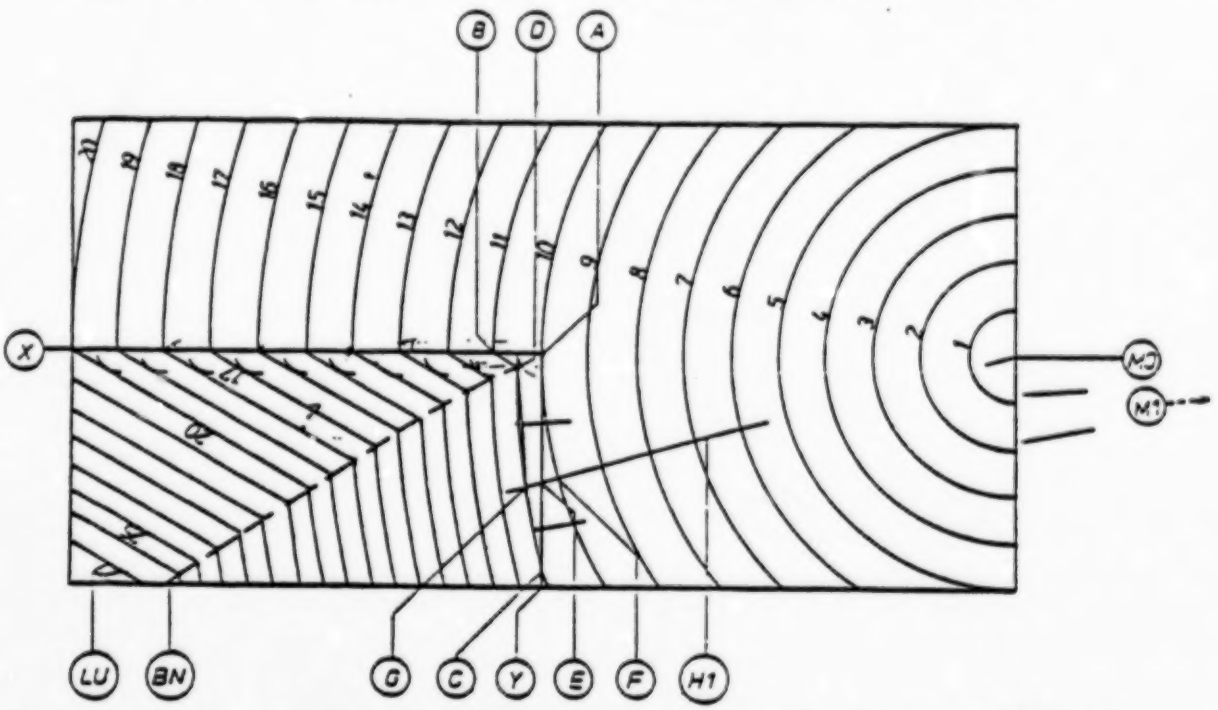


FIGURE 17: Flow pattern for the plate with varying wall thickness.

$$Kt = T2 / T1 \qquad (2)$$

where

T1 = the wall thickness of the reference flow path
T2 = the wall thickness of the new path

If the step in the reference area St1 is 7 mm, for example, the step length St2 in the new area will be:

$$St2 = Kt * St1 \qquad (3)$$

For the example of the plate, this gives

$$St2 = (T2 / T1) * St1 = (1 / 2) * 7 = 3.5 \text{ mm}$$

At flow front No. 11, the melt flows not only centrally, parallel to A-X up to point B, in the 2 mm thick area, but into the smaller wall thickness region, across the boundary between points A and B. The line representing this overflow is the straight line from B to D, where it is tangent to an arc about A with a radius of St2 (Fig. 17). All other flow lines representing overflow into the thin region along line A-X, will be at the same angle as the vertex ABD (region 2).

The tangent method describes the overflow in areas of smaller part thickness quite well, although a slightly different behavior will be exhibited around irregularities such as corners.

Another overflow into the thinner section will occur between points A and Y. The curve between the points C and D will an arc determined by flow front No. 10 and the boundary line A-Y. Two methods can be used to determine the center of the arc AC.

3.2.6 Information Provided By The Flow Pattern

Three main pieces of information are provided by the flow pattern for the evaluation of moulds or processing parameters:

1. Number and position of weld lines
2. Number and position of air inclusions (venting)
3. Homogeneity of the mould filling.

3.2.6.1 Weld Lines -

A weld line (line BN, Fig. 17) is formed in the thinner region of the mould where the two melt streams that cross the lines AY and AX meet.

3.2.6.2 Venting -
At the end of the filling phase, the air that remains in the cavity is compressed into area LU (Fig. 17).

3.3 PRESSURE BALANCE

The program "Basic Geometries", with the help of the flat pattern, determines the number and positions of the weld lines and air inclusions (voids). The elimination of these weld lines and air inclusions (voids) is achieved by means of variations in wall thicknesses and the repositioning of gates into non-critical areas.
To assure a good quality moulded part, the following operating criteria must be respected:

1. Pressure peaks during the filling phase must be eliminated.

2. All extremities in a single cavity mould should be filled at the same time, to avoid overpacking, which leads to geometrical distorsions. This is particularly critical for a cavity with several injection points. A pressure compensation and optimizating method is required.

3. For a multi-cavity mould, all parts should be filled at approximately the same time. Here too, a pressure compensation method is useful.

4. Cooling times for different zones in a cavity should not be too different, so as to minimize variations in shrinkage of the part. An analysis of the cooling time, as well as the required cooling circuits, is necessary to optimize the cooling process.

The operating criteria required for a successful filling process can usually be achieved by improving the pressure compensation. Better pressure compensation also greatly simplifies the adjustment of the machine operating parameters, since varying the parameters based on the position of the screw is not necessary for uniform filling. Only two adjustments of the machine operating parameters are required:

1. Switching from the filling to the holding (or packing) pressure.

2. Reducing the speed of the screw at the end of the filling phase to reduce the high shear stresses (see Limitations To The Simulation).

Once the moulds and gate systems are rheologically well designed, the entirerange of the adaptability of modern injection moulding machines is available for further improvements in the quality of the part.

As mentioned in the introduction, the pressure compensation is carried out in order to assure equal pressure drops over all flow paths with equal filling times. As we will later describe in detail, the pressure compensation is compared to a reference flow path with the pressure loss already determined by the given mould geometry, assuming constant injection speed and melt viscosity. Pressure losses along the other flow paths are matched to this reference flow path.

In addition, the pressure compensation method offers the possibility of choosing a value for the reference pressure or pressure drop, instead of comparing to a reference flow path for which the pressure drop can no longer be influenced by a change in geometry. In this mode, the geometries of all flow paths are allowed to change so as to produce the desired value.

Both methods of pressure compensation assure that the cavities or sprue systems are filled in equal times. The methods differ merely in their optimizing aims.

Pressure compensation by means of a reference flow path will be described first.

3.3.1 Pressure Compensation In The Delivery System

After designing and optimizing the mould, the next step is the dimensioning of the sprue. The filling conditions must be approximately the same for all cavities, particularly when using multiple moulds with symmetrical cavities, where the flows of the molten material vary from place to place inside of the sprue system.

There are two main types of runners: cold runners and hot runners.

Cold runners are generally designed to achieve equal filling times for all cavities. When the injection cycle begins, some time is lost while filling the runners. This time is different for different runner lengths.

Hot runners are generally designed to insure equal volume flow rates. This is due to the fact that the filling of the cavities begins simultaneously as soon as the screw starts moving.

The sprue has a minimal conicity (4 degrees generally), whereas the sprue distributor systems lying in the plane of the mould halves interface are not conical, for reasons connected with demoulding. A simulation of the sprue system with the help of cylinders is generally sufficient. More precision can be achieved by using cylinders with differents diameters.

Fig. 18 presents a summary of the criteria for the design of sprue systems. Five rheological criteria are described.

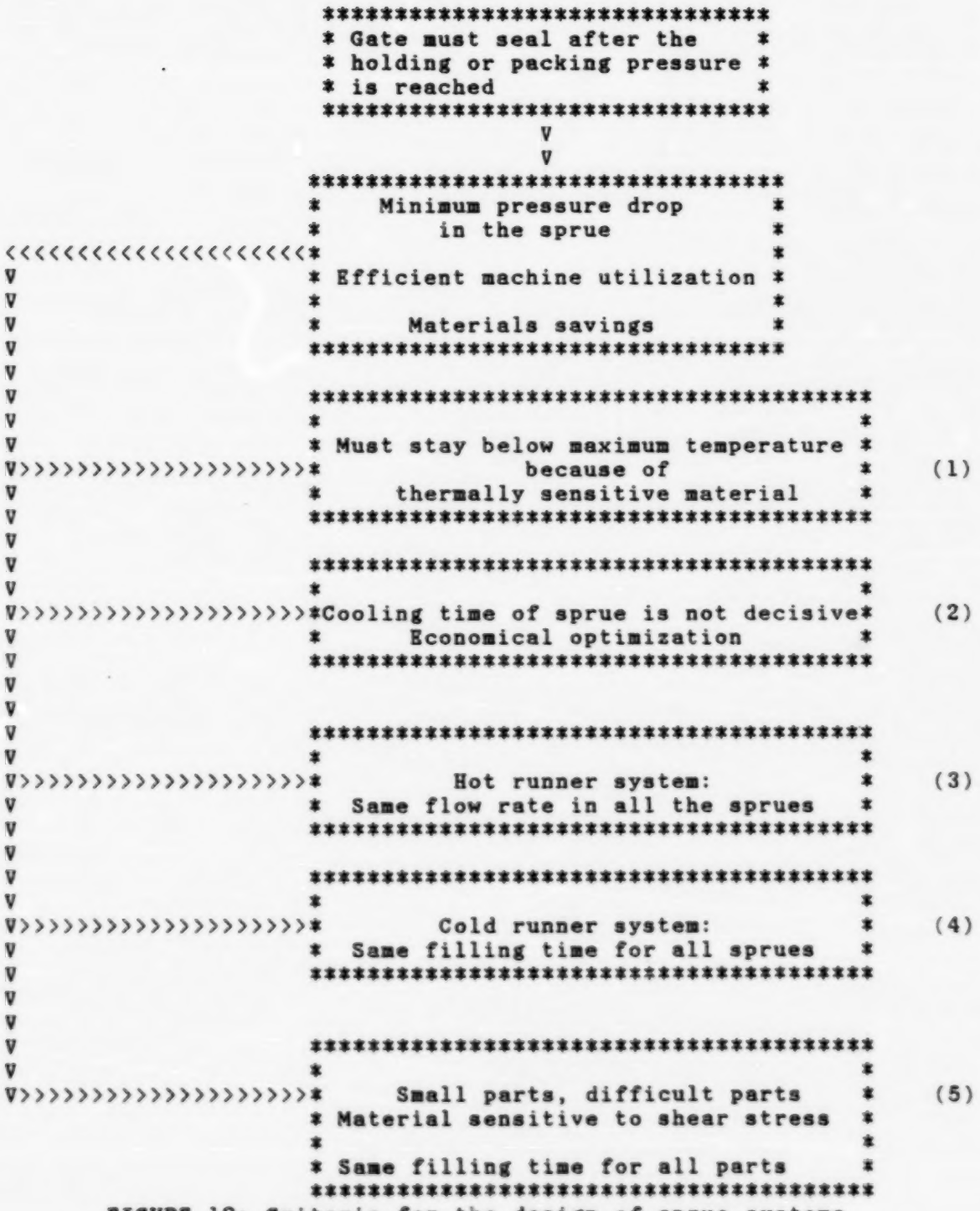

Gate must seal after the holding or packing pressure is reached
Minimum pressure drop in the sprue
Efficient machine utilization
Materials savings
Must stay below maximum temperature because of thermally sensitive material
(1)
Cooling time of sprue is not decisive
Economical optimization
(2)
Hot runner system:
Same flow rate in all the sprues
(3)
Cold runner system:
Same filling time for all sprues
(4)
Small parts, difficult parts
Material sensitive to shear stress
Same filling time for all parts
(5)

FIGURE 18: Criteria for the design of sprue systems

CHAPTER 4

MOULD THERMAL ANALYSIS

4.1 INTRODUCTION

The design of a mould cooling system is of great importance to both the production efficiency and quality of the moulded part.

Efficient production is provided by short cycle times. The quality of the moulded part is determined by the quality of the cooling system layout and performance.

- The quality of the part surface is influenced by the mould temperature
- Temperature differences along the part surface cause inhomogeneous properties and distortion, increasing the danger of residual stress and stress-corrosion.

Therefore, the objective of cooling is to evenly cool the material from the melt temperature in order to produce a homogeneous part. This is to be accomplished in the shortest time possible, without the diminished surface quality that results when the mould temperature is too low.

The mould must be designed for safety, reliability as well as the best possible thermal transfer so that maximum production combined with maximum part quality can be achieved.

The steps in the design of a cooling system are:

- heat flow balance for the whole mould
- flow rate of the cooling liquid
- positioning the cooling circuit
- cooling liquid pressure drop calculation

4.2 CALCULATION OF THE COOLING TIME

4.2.1 Plates

The first step in the design of the cooling layout, or thermal layout is the calculation of the required cooling time. At time t = 0, the material is injected at a melt temperature Theta(m).

A temperature profile through the cross-section of the part is established after the cooling time Tk (Fig. 19). The part temperature at ejection can be one of the following:

- the temperature in the center of the part, which is the maximum temperature in the part
- the average of the integrated value across the thickness,

The relation between time and the temperature profile in the part is described by the differential equation of the temperature field. For a one-dimensional heat flow, this is:

$$\frac{d^2(\mathrm{Theta})}{d^2(X2)} = \frac{1}{A} * \frac{d(\mathrm{Theta})}{d(T)} \qquad \text{(eq. 1)}$$

This differential equation can be solved by a Fourier-progression with simplified boundary conditions.

Boundary conditions:

1. Immediately after injection, the melt imposes a constant temperature along the mould wall
2. The mould temperature is considered constant
3. The thermal diffusivity is considered constant

For plates with length/thickness ratios greater than 10, /ref. 1/ this results in:

$$\text{Theta} - \text{Theta(w)} = \frac{4}{\text{Pi}} * [\ \text{Theta(m)} - \text{Theta(w)}] * \text{Sigma}$$

Where: Sigma =

$$\text{Sum}_{n=0}^{n=\text{Infinity}} \frac{(-1)}{(2*n+1)} * \text{Exp}[-A*(2*n-1)^2 * \text{Pi}^2 * t]/S^2 * \text{Sin}\frac{(2*n+1)*\text{Pi}*X}{S}$$

Considering only the first term results in equation 40.7:

$$\frac{\text{Theta(e)} - \text{Theta(w)}}{\text{Theta(m)} - \text{Theta(w)}} = \frac{4}{\text{Pi}} * \text{Exp}[-A * \text{Pi}^2 * \text{Tk} /(S^2)] * \text{Sin}[\ \text{Pi}*X/S]$$

(eq. 40.7)

The error introduced by:

- the dependency of Theta(m) on x at t = 0
- a varying Theta(w) from t = "nul" until T = Tk
- and the dependency of 'A' on temperature

is corrected by using a value 'Aeff' , which is the effective thermal diffusivity determined by measurements /ref. 2/. The melt temperature at the nozzle is used for Theta(m) , and a temperature Theta(m) averaged over the cooling time is used for Theta(w). With the ejection temperature averaged from x = 0 to x = s/2, eq. 40.7 is simplified to eq. 40.8:

$$\text{Tka} = \frac{S^2}{(\text{Aeff}* \text{Pi}** 2)} * \text{Ln}[\ \frac{8}{\text{Pi}**2} * \frac{\text{Theta(m)} - \text{Theta(w)}}{\text{Theta(e)} - \text{Theta(w)}}\ ]$$

(eq. 40.8)

When a maximum ejection temperature is preferred:

$$\text{Tk} = \frac{S^2}{\text{Aeff}* \text{Pi}**2} * \text{Ln}\ [\ \frac{8}{\text{Pi}**2} * \frac{\text{Theta(m)} - \text{Theta(w)}}{\text{Theta(e)} - \text{Theta(w)}}\ ]$$

(eq. 40.9)

When the part contains regions with different wall thicknesses, the cooling time is determined from the area with the thickest wall, since this area must be solidified when the part is ejected.

The cooling time required for cylinders (e.g. sprues) can be calculated with similar equations (see chapter 2.1.3). If it is assumed that the sprue must be at the same temperature as the plate when the part is ejected, a minimum and a maximum sprue diameter is calculated.

The measurement of the effective thermal diffusivity can be determined with the following experimental set-up:

The following values are measured while moulding a simple geometry:

- Melt temperature at the nozzle (Theta) M
- mould temperature averaged over the cooling time (Theta bar) W

Immediately after ejection, the part is insulated along both surfaces in order to determine the average ejection temperature. Assuming no heat loss through the insulation, the initial temperature profile at t = t K will become the final temperature profile at t = (infinity), where the entire part is at the average ejection temperature (Theta bar) E (see Fig. 20). The effective thermal diffusivity can then be calculated from:

$$Aeff = \frac{S^2}{Tk * Pi^{**}2} * Ln\left[\frac{8}{Pi^{**}2} * \frac{Theta(m) - Theta(w)}{Theta(e) - Theta(w)} \right]$$

Effective thermal diffusivity values are given for two groups of materials in Figs. 21 and 22.
p;Table 1 presents reference values for melt, mould and ejection temperatures, as well as average densities.

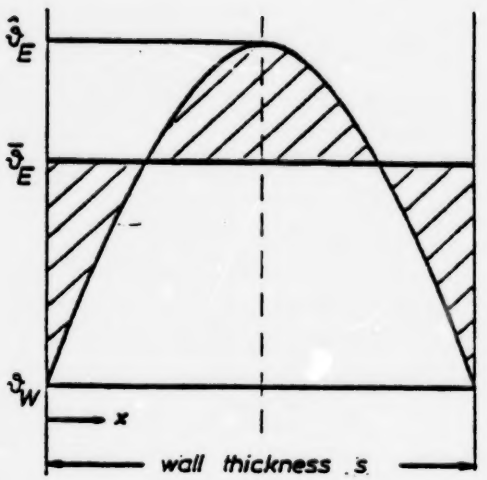


FIGURE 19: Temperature profile in the part at the ejection time

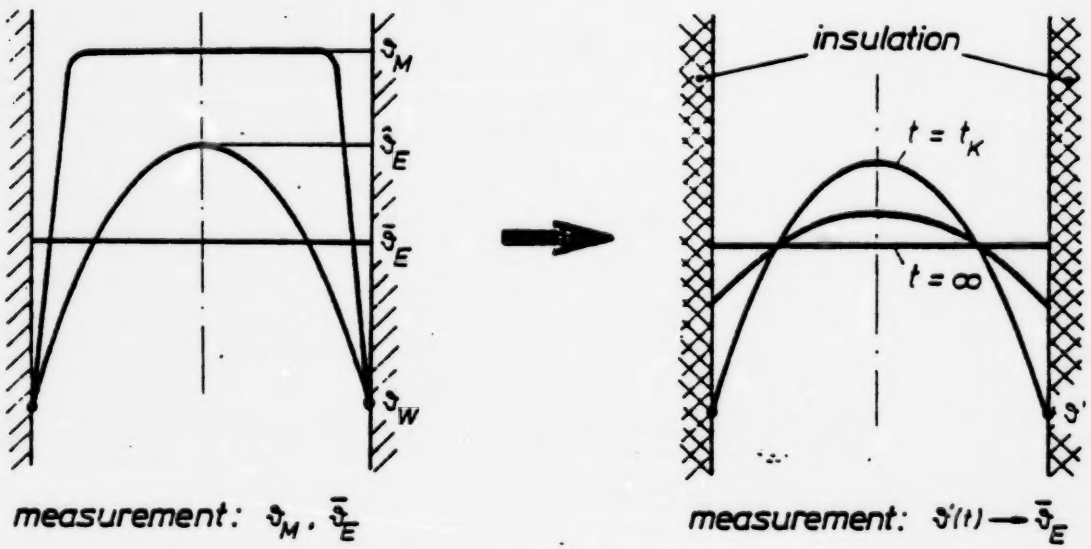


FIGURE 20: Measurement of the effective thermal diffusity

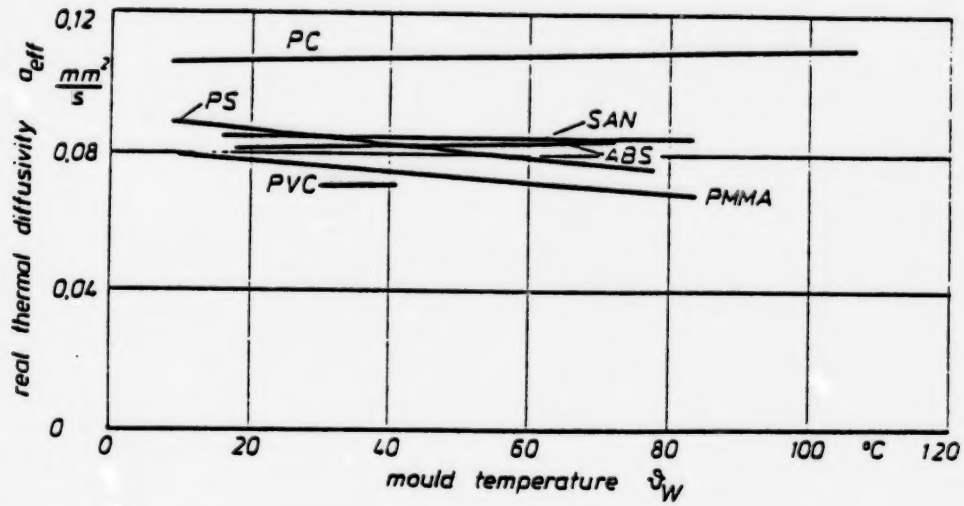


FIGURE 21: Effective thermal diffusivity for various amorphous materials

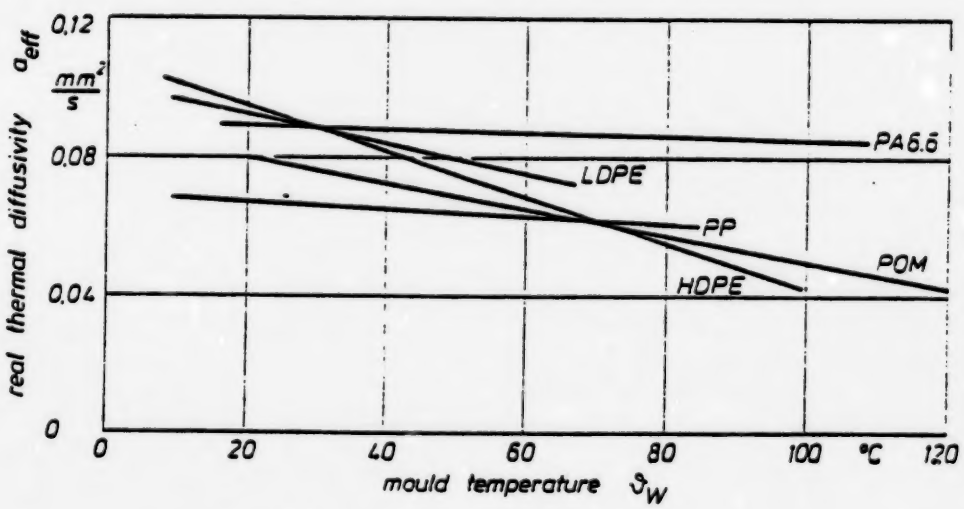


FIGURE 22: Effective thermal diffusivity for various semi-crystalline materials

Material	Melt temp. (C)	mould temp. (C)	Eject. Temp. (C)	Average Density (g/cm3)
ABS	200-280	40- 80	60-100	1.03
PC	260-320	85-120	90-140	1.14
PMMA	200-280	40- 80	110	1.14
PS	180-250	10- 50	60-100	1.01
SAN	180-260	40- 80	60-110	1.05
HDPE	240-290	15- 50	60-110	0.82
LDPE	180-240	15- 50	50- 90	0.79
PQM	170-210	60-120	90-150	1.3
PP	220-290	20- 90	60-100	0.83
PVC	180-210	20- 60	60-100	1.35
PA 6.6	250-320	40-120	70-140	1.05

Table 1: Melt, mould and ejection temperatures for various materials

4.3 COOLING CIRCUIT ANALYSIS

4.3.1 HEAT FLOW BALANCE

The following general equation applies:(See fig. 23)

$$Qks + Qtm + Qu + Qad = 0 \qquad (43.6)$$

where

Qu is the heat flow with the surroundings
Qu = Qko + QRad + QLei
Qks = Heat flow of moulded part
Qtm = Heat flow of cooling liquid
Qad = Additional heat flow (e.g. hot runner)

Qko = Convective heat flow
QRad = Heat flow by radiation
QLei = Heat flow by conduction

NOTE: All heat flows into the mould are positive and all heat flows out of the mould are negative.

4.3.1.1 Heat Flow Of The Moulded Part (Qks) -

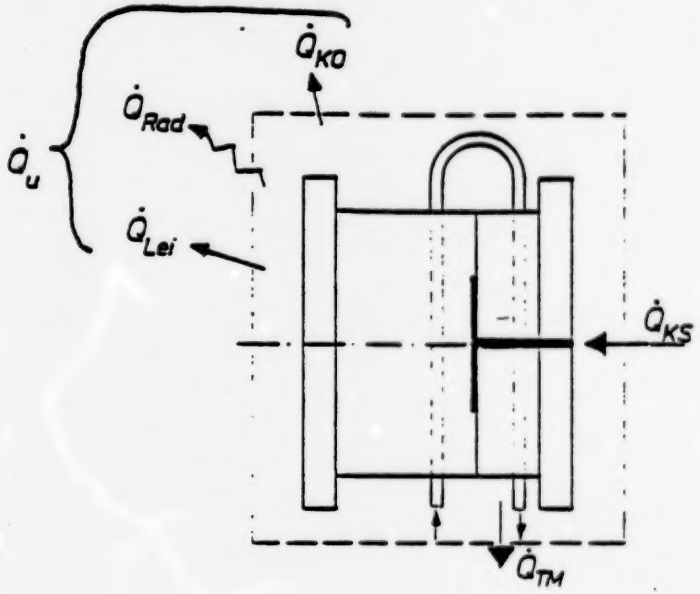


FIGURE 23: Heat flow balance

$$Qks = \frac{Delta(h) * Delta(ks) * Vtf}{tk + tn}$$

(eq. 43.1)

where

Qks	=	Heat flow of moulded part (moulding) (Always positive)
Delta(h)	=	Enthalpy difference (see Figs. 24 and 25)
Delta(ks)	=	Density of plastic material
Vft	=	moulding volume
tk	=	Cooling time
tn	=	Additional time

4.3.1.2 Convective Heat Flow (Qko) -

There is a heat flow (Q u) to the surroundings due to convection at the mould's lateral surfaces. If the temperature there is higher than the ambient temperature, these heat flows are negative, since heat is removed from the mould.

$$Qko = As * Alpha * (Theta(u) - Theta(wa))$$

where

As	=	The mould's lateral surface area
Alpha	=	Heat transfer coefficient for free convection in air (empirical value of 15 W/m2K)
Theta(wa)	=	Temperature of the mould's lateral surfaces
Theta(u)	=	Ambient temperature

4.3.1.3 Heat Flow By Radiation (Qrad) -

$$Qrad = As * Eps * Cs * [(Tu / 100)^4 - (Twa / 100)^4]$$

(eq. 43.3)

where

As	=	The mould's lateral surface area
Eps	=	Coefficient of emission (e.g. for blank steel: 0.25)
Cs	=	Radiation constant (Cs = 5.77 W/m2/k)

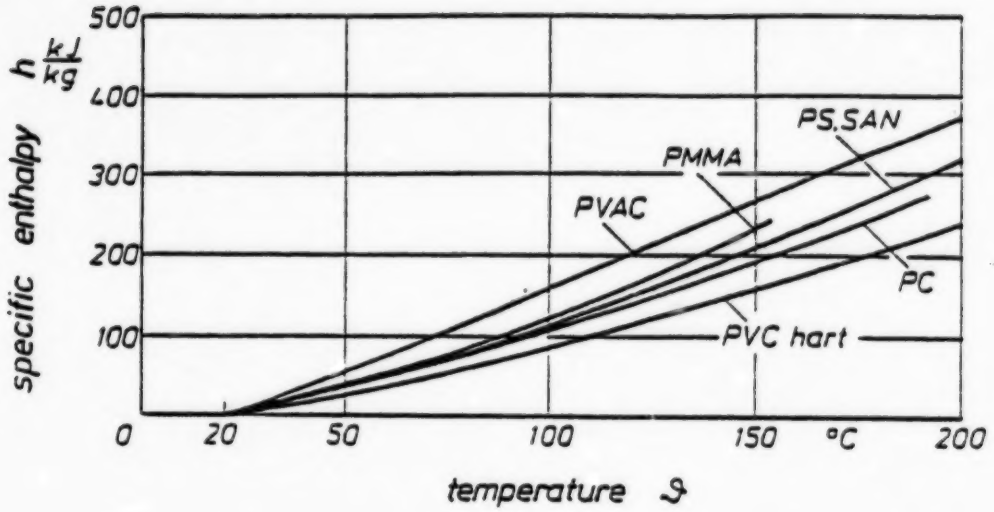


FIGURE 24: Specific enthalpy for amorphous thermoplastics

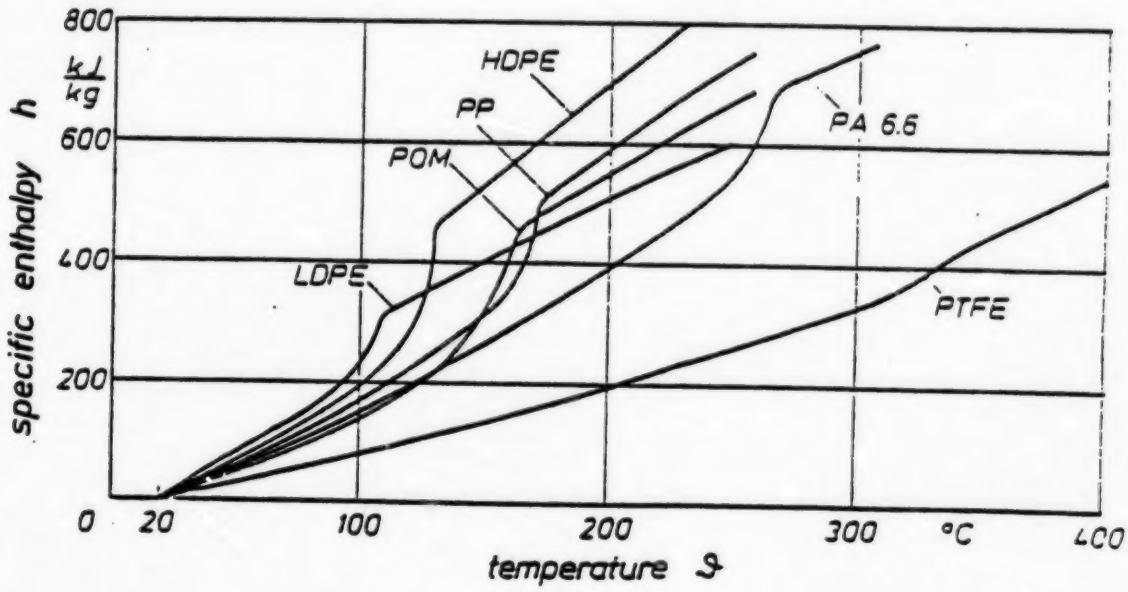


FIGURE 25: Specific enthalpy for semi-crystalline thermoplastics

Twa = Absolute temperature of lateral surfaces Of the mould (Kelvin degrees)
Tu = Absolute ambient temperature (Kelvin degrees)

4.3.1.4 Heat Flow By Conduction -

The heat flow by conduction to the mould plattens is calculated with the help of a proportionality factor

$$Qlei = Al * Beta * [Theta(u) - Theta(wa)]$$

(eq. 43.4)

where
Al = The total surface area of both clamping plates
Beta = Proportionality factor e.g.

Unalloyed steels	100 W/m2 C
Low alloyed steels	100 W/m2 C
High alloyed steels	80 W/m2 C

4.3.1.5 Heat Flow With The Surroundings (Qu) -

$$Qu = Qko + Q\,ad + Q\,ei$$

4.3.1.6 Heat Flow With The Cooling Liquid -

From equation 43.6:

$$Qtm = - Qks - Qu - Qrad$$

4.3.1.7 Heat Exchange Factor (Cq) -
For Qtm < 0 :Cooling, heat removed from the mould by cooling liquid
For Qtm > 0 :Heating, heat supplied to the mould by cooling liquid

The operating point can be specificed by the factor Cq (see Fig. 26), which is the ratio of the heat flow to the surroundings divided by the heat flow from the part

$$Cq = \frac{Qu}{Qks} \qquad \text{(eq. 43.7)}$$

According to either the volume or direction of the particular heat flows, three characteristic operating ranges of the cooling system can be specified:

1. $0 < Cq < (\text{infinity})$
   See Fig. 27 Heat balance (Case 1)

The temperature of the mould's lateral surfaces: Theta(wa) is below the ambient temperature: Theta(u) . Hence, heat flows from the environment into the mould (Qu). If Cq = 0, then Theta(wa) = Theta(u) and no heat exchange occurs. In this case, the cooling agent has to remove the heat flow Qks .

2. $-1 < Cq < 0$
   See Fig. 28: Heat balance (Case 2)

The temperature: Theta(wa) is higher than the ambient temperature Theta(u) . There is a heat flow from the mould to the environment, which is negative since it is removed from the mould. This flow reduces the heat that the cooling agent must remove.

3. $-(\text{infinity}) < Cq < -1$
   See Fig. 29: Heat balance (Case 3)

So much heat flows from the mould to the environment that additional heat must be supplied by the cooling agent. Thus the cooling system heats the mould.

Insulating the mould surface reduces the heat flow to or from the environment, Qu . Thus, the angle Gamma is increased (Fig. 30).

If, without any insulation, the operating point is located in area 1, i.e. heat is flowing from the environment into the mould, the temperature control agent has to remove less heat when insulation is provided. This means, that a cooling device with a lower cooling power can be used. With insulation, the point Qks = Qu is shifted towards higher channel temperatures.

When the operating point, without insulation, is located in area 3, i.e. heat must be supplied by the cooling liquid to compensate for the high losses to the environment, insulation may lower the required heat provided by the cooling liquid, or even make it unnecessary. If, in this case, no additional heat is provided by the cooling liquid, then any variations of the ambient temperature entails a change in the amount of insulation, to maintain the desired cooling time. Independence from ambient temperature changes is increased by insulating moulds. This is illustrated by the increased angle (Gamma)

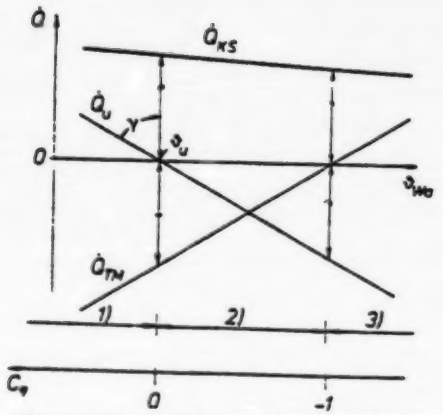


FIGURE 26: Characteristic operating ranges

1. $0 < C_q < \infty$

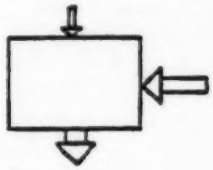


FIGURE 27 Heat balance (Case 1)

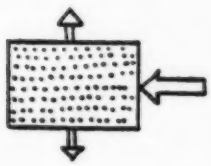


FIGURE 28: Heat balance (Case 2)

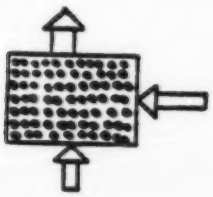


FIGURE 29: Heat balance (Case 3)

on Fig. 30.

Another problem in determining the heat flow balance is that the actual mould dimensions are not yet known. Initially, estimations can be used; after the mechanical design of the mould is finalized, the heat flow balance can be verified.

The initial surface temperature of the mould can be set equal to the temperature of the cooling liquid, as a first approximation.

4.3.2 Cooling Liquid Flow Rate

A hot mould causes a temperature increase in the cooling liquid (temperature control liquid) between inlet and outlet of the cooling circuit (cooling circuit). The expression for the heat flow Qtm is:

$$Qtm = Vf * Delta(Theta) * Rho(tm) * Ctm$$

Upon re-arranging this equation, the cooling liquid volume flow rate, V, is:

$$Vf = \frac{Qtm}{Rho(tm) * Ctm * (Theta(o) - Theta(i))}$$

where

Qtm	=	the heat flow into cooling liquid
Vf	=	the volume flow rate of the cooling liquid
Theta(o)	=	the outlet temperature of the cooling liquid
Theta(i)	=	the inlet temperature of the cooling liquid
Rho(tm)	=	the density of the cooling liquid
Ctm	=	the heat capacity of the cooling liquid

Since a constant and continuous cooling between the inlet and the outlet is required, a temperature difference can be chosen and the volume flow rate Vf determined.

Another requirement is that the flow in the cooling liquid should be turbulent. This is the case for water when the Reynolds number is greater than 2320.

$$Re = \frac{4 * V}{Nu * Pi * d}$$

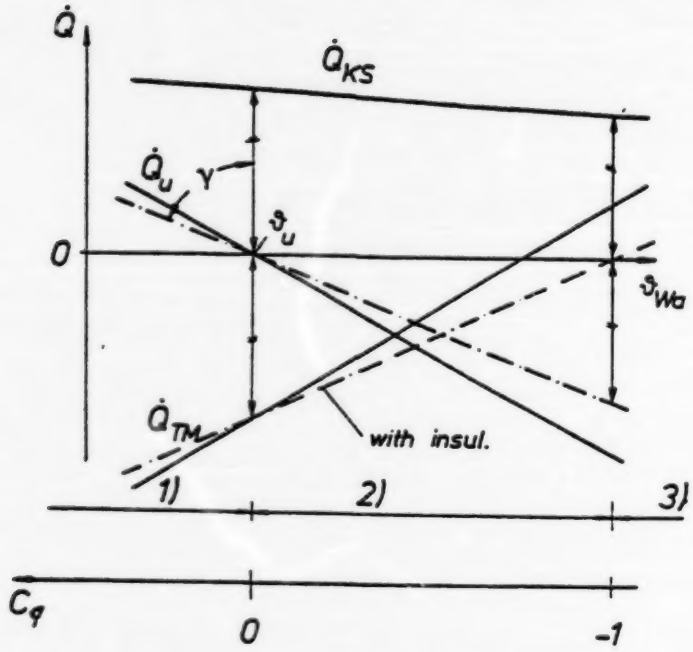


FIGURE 30: Effect of insulation

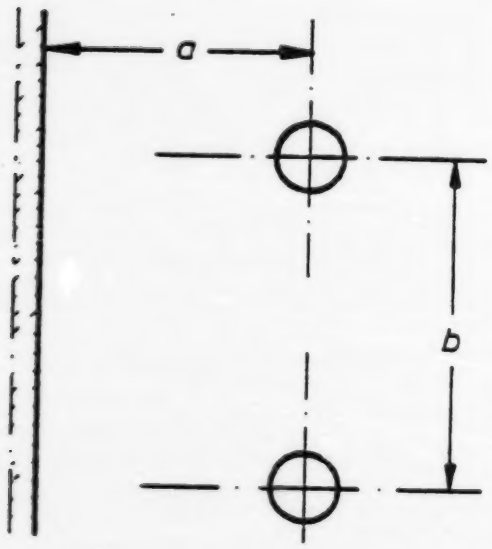


FIGURE 31: Positions of the cooling channels

where
Nu = the kinematic viscosity
d = the diameter of cooling channel
A maximum cooling channel diameter, d max, for a given cooling liquid flow rate V, can be calculated.

$$Dmax = \frac{V}{1822*Nu}$$

For a desired change in the temperature of the cooling liquid, [Delta(Theta) max], the minimum cooling liquid volume flow rate can be calculated. After the cooling channel diameter is determined, (smaller than Dmax), the Reynold number, Prandtl number, Biot number and the coefficient of heat transfer can be calculated as follows, /ref. 4/

$$Pr = \frac{Nu * Rho(tm) * Ctm}{Lambda(tm)} \qquad \text{(eq 43.11)}$$

where
Pr = the Prandtl number
Nu = the kinematic viscosity
Rho(tm) = the cooling liquid's density
Ctm = the cooling liquid's thermal capacity
Lambda(tm) = the cooling liquid's thermal conductivity

$$Alpha = \frac{Lambda(tm)}{D} * [\ Re^{.75} - 180\ ]*0.037 * Pr^{.42}$$

(eq 43.12)

where
Alpha = the coefficient of heat transfer
D = the cooling channel diameter

$$Bi = \frac{Alpha * D}{Lambda(w)}$$

(eq 43.13)

where

Bi = the Biot number
Lambda(w) = the thermal conductivity of the mould material

The physical and thermal properties of the cooling liquid depends on the temperature /ref. 5/. They can be calculated from the polynomial law based on the information in the material data base.

4.3.3 Positioning Of The Cooling Channels

Two variables specify the positions of the cooling channels (see Fig. 31).

a = the distance between the surface of the cavity and the cooling channel
b = the distance between two cooling channels

The positionning of the cooling channels is based on various criteria:

1. Sufficient heat flows in the cooling circuit
2. The desired temperature distribution in the mould
3. Low production costs

The details to each criterium follow.

1. Sufficient heat flows in the cooling circuit
   The positions of the cooling channels must guarantee that the desired amount of heat flows between the part and channel wall. The heat transfer is described by:

$$Qtm = -Alpha * Atk * [Theta(tm) - Theta(tk)]$$

where
Qtm = Heat flow in the cooling liquid
Alpha = the coefficient of heat transfer
Theta(tm) = the temperature of the cooling liquid
Theta(tm) = the temperature at the cooling channel wall
Atk = a cross-sectional surface area parameter of the temperature control channel

The equation for AS TK is:

$$Atk = Pi * D * L \qquad \text{(eq 43.15)}$$

where $L = \frac{\pi}{b}$ (eq 43.16)

where
D = the cooling channel diameter
L = the effective total cooling channel length
Aft = the part surface area

The equation for heat conduction of the cooling liquid is:

$$Qks = -\bar{Lambda(w)} * Aft * \frac{[Theta(w) - Theta(tk)]}{a}$$

(eq 43.17)

where
Qks = the heat flow from the part that must be removed
Lambda(w) = the thermal conductivity of the mould material
Theta(w) = the mould temperature
a = the distance between the cavity surface and the cooling channels

Combining equations 43.15 and 43.17 gives the relation between the distances a and b.

$$\frac{Qks}{Lambda * Aft} * a - \frac{Qtm}{Alpha * Pi * D * Aft} * b = Theta(tm) - Theta(w)$$

(eq 43.18)

This linear equation a = C1 + (C2 * b) shows that the desired heat flows Qks and Qtm can be achieved with various cooling system geometries (Fig. 32).

Any combination of a and b that lies on the line generated in a graph similar to Fig. 32 is capable of providing the desired heat flows; however, achieving the desired temperature distribution places additional limits on these values.

2. The desired temperature distribution in the mould

The temperature distribution in the mould can be described by the heat flow profile in Fig. 33, where q is the heat flow per unit area. Regions located between the cooling channels are not cooled as much (Qmin) as regions immediately beside the channels (Qmax).

The difference between q min and q max will be increased by high values of b as well as low values of a.

The temperature distribution at the cavity surface can be evaluated by the cooling error j, which is defined as

$$j = \frac{Qmax - Qmin}{(Qmax + Qmin) / 2}$$

The relationship between j and a and b is:

$$j = 2.4 * (Bi)^{0.22} * (b/a)^{2.8} * \ln (b/a) \qquad \text{(eq 43.19)}$$

The cooling error limits are:

j < 2.5 to 5% for semi-crystalline materials
j < 5 to 10% for amorphous materials

Thus, a and b are limited as shown in Fig. 34.

3. Low production costs

The larger the distance between channels (b), the fewer the number of channels are required. However, from Fig. 32, the larger the value of b, the less the value of a, the distance between the cavity surface and the cooling channels. Of course, a and b must be choosen so that the cooling error is less than the cooling error limits for the material being moulded.

The positioning of the cooling channels can be determined with the following procedure:

1. typical values given to distance b and Theta(tm) (cooling liquid temperature)
2. total effective channel length L calculated
3. distance a calculated
4. cooling error j calculated

Alternatively,

1. typical values given to distances a and b (j must be in appropriate range for the material being moulded)
2. Theta(tm) (cooling liquid temperature) calculated

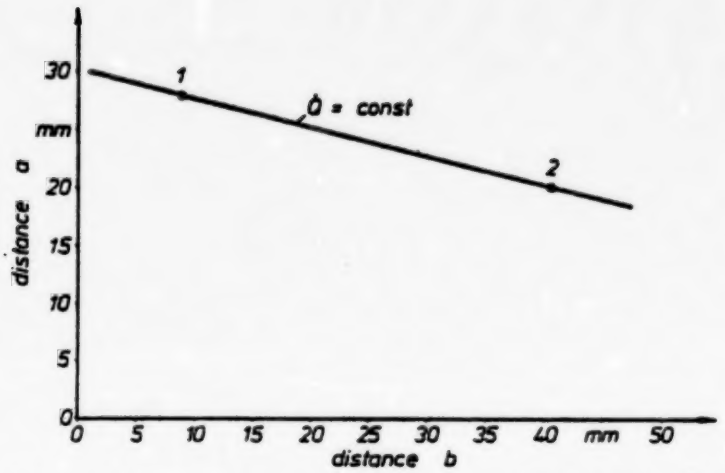


FIGURE 32: Achieving the desired constant heat flows

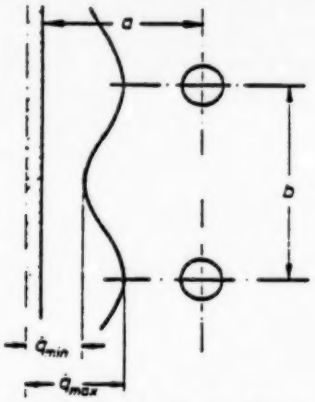


FIGURE 33: Variations in the heat flow between a cavity and the cooling channels

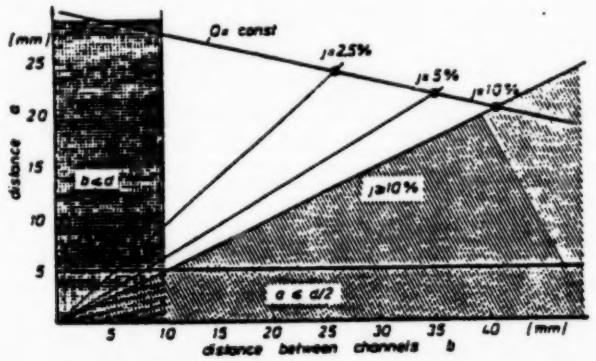


FIGURE 34: Limits to a and b

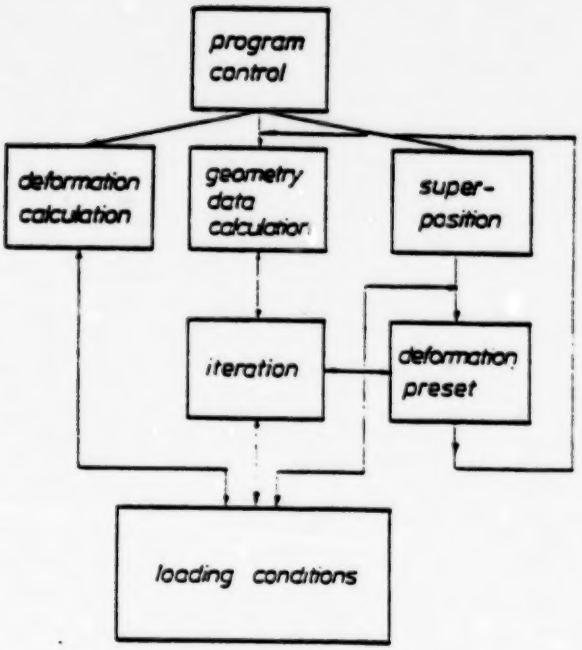


FIGURE 35: Diagram of the mechanical calculation program

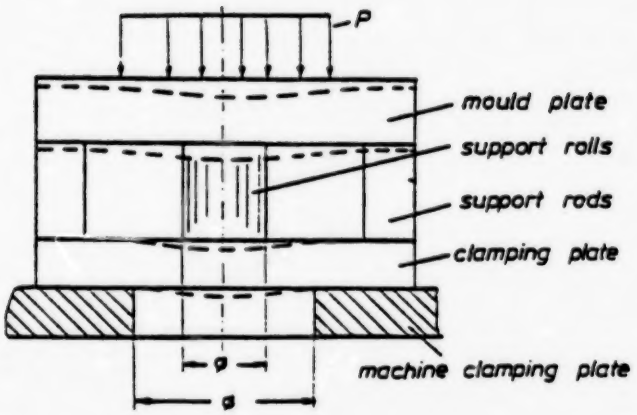


FIGURE 36: Deformation of the moveable mould half

3. heat flow balance calculated

This last method must be iterated until the desired heat flow balance is achieved.

When the total effective channel length was calculated, it was assumed that any values for the distances a and b could be used. However, in reality, certain mechanical parts of the mould, e.g. ejectores, junction planes, may be interfere with the placing of the cooling channels.

When the production cost can be ignored, a wide range of combinations of the distances a and b are feasible. Under these circumstances, the program can generate a table of various combinations of a, b and j, from which suitable values for a given case can be choosen.

4.3.4 Calculation Of The Pressure Drop In The Cooling Circuit

After the lay-out of the cooling circuit is determined, the pressure drop between the inlet and outlet must be calculated. The pressure drops along the channel length and due to elbows and other fittings must be considered.

The pressure drop can be calculated as follows:

$$\Delta p = \Psi * \frac{\rho_{tm} * v_a^2}{2} \qquad \text{(eq 43.20)}$$

where

- Δp = the pressure drop in the cooling liquid
- Ψ = the coefficient of the pressure drop for a given fitting
- ρ_{tm} = the density of the cooling liquid
- v_a = the average shear velocity of the temperature control liquid

The values for the coefficient of the pressure drop for various fittings (Ψ) are:

FITTING	Ψ
straight tubes (L = length and d = diameter)	0.04*(L/d)
90 degree corners (sharp corners)	1.9

90 degree elbows (round corners)	0.4
other fittings	2 to 5

With this equation, particular pressure drops at various positions in the circuit can be calculated.

Delta(Pl) = pressure drop along the channel length
Delta(Pc) = pressure drop in corners
Delta(Pe) = pressure drop in elbows
Delta(Pf) = pressure drop in fittings
Delta(Ptot) = total pressure drop

If the total pressure drop is too high, it can be reduced by reducing the volume flow rate V or by increasing the cooling channel diameter d min.

The respective limits are:

$$Vmax = [\ Delta(Pmax) / Delta(Pges)]^{0.5} * Va$$

$$Dmin = [\ Delta(Pmax) / Delta(Pges)]^{0.25} * D$$

If either of these values are changed at this point, the entire temperature control system must be re-analysed.

4.3.5 Calculation Of The Total Power Required By The Cooling System

Once the total pressure drop is known, the total power required by the cooling system can be calculated.

Pth	=	Qtm	(Thermal power)
Ppr	=	Delta (Ptot)	(Pumping power)
Ptot	=	Pth + Ppr	(Total power)

CHAPTER 5

MOULD MECHANICAL ANALYSIS

5.1 INTRODUCTION

As moulded plastic parts and their moulds become larger, deformations in the mould and inside the moulding machine become more significant. The determination of these deformations also becomes more important; failure to take such deformations into account during the design stage can lead to reduced part quality and/or production rates.

There are two kinds of deformation:

1. Deformation in the locking direction (e.g. bending of the floating plate between the supporting bars)

2. Deformation at right angles to the locking direction (e.g. cavity expansion)

Deformations in the locking direction may cause a gap between the mould halves, along the parting line. If the gap becomes too large, material may escape from the cavity into the gap, resulting in flash along the article's parting line. Flash can also cause damage to the mould, since the entire clamping force is concentrated on the flash areas along the interface of the mould halves. If the pressure is sufficient to leave imprints on the interface, the gap width becomes even greater and flashing increases. Re-machining the mould only makes sense if the deformations in the locking direction can be eliminated or sufficiently reduced at the same time, e.g. by using a supplementary floating plate in order to stiffen the mould.

Admissible gap width values are:

- Semicrystalline thermoplastics 0.015 - 0.02 mm

- Amorphous thermoplastics 0.02 - 0.03 mm

The internal pressure in the mould causes compression of the mould core (f_K) and expansion of the cavity (f_N). During cooling, the mould shrinks in thickness direction (s_d), compensating for the deformations. There should be no forces between the cavity and the part, at right angles to the closing direction,

when the part is ejected, otherwise,

- The mould is difficult or impossible to open,
- The part is damaged while opening the mould, or
- The part is difficult or impossible to remove without damaging it.

The limiting value for the deformation at right angles to the closing direction is:

$$(Ff + Fn) < Sd$$

Including calculations of the deformations in the mould in the design stage can

- Reduce the amount of re-machining of the mould
- Improve the quality of the moulded part
- Avoid damage to the mould and reduce the resulting downtime

This mechanical design program enables the user to carry out fast and simple calculations of mould deformations. In addition, mould dimensions can be calculated based upon maximum deformations at chosen locations within the mould. Superposing calculations of individual elements permit the determination of the deformation in the entire mould. This superposition is done by the program; the user only enters the data for the individual elements and their configurations in the mould.

The following chapters describe the fundamentals of the deformation calculation for single elements. Fig. 35 shows the synopsis of various calculation options for the mechanical design.

5.1.1 Deformation Of The Mould In The Closing Direction

Fig. 36 illustrates some of the deformations induced in a mould in the closing direction by internal pressures in the cavity. The mould and backing plates are subjected to bending and shearing; when rectangular support rods are used, the loading conditions can be considered as "clamped on two sides". The support rods and support rolls are compressed. The mould clamping plates are "clamped along their perimeters" when lying above the cut-out of the machine clamping plate. This simple example shows that the deformed mould elements must be characterized by:

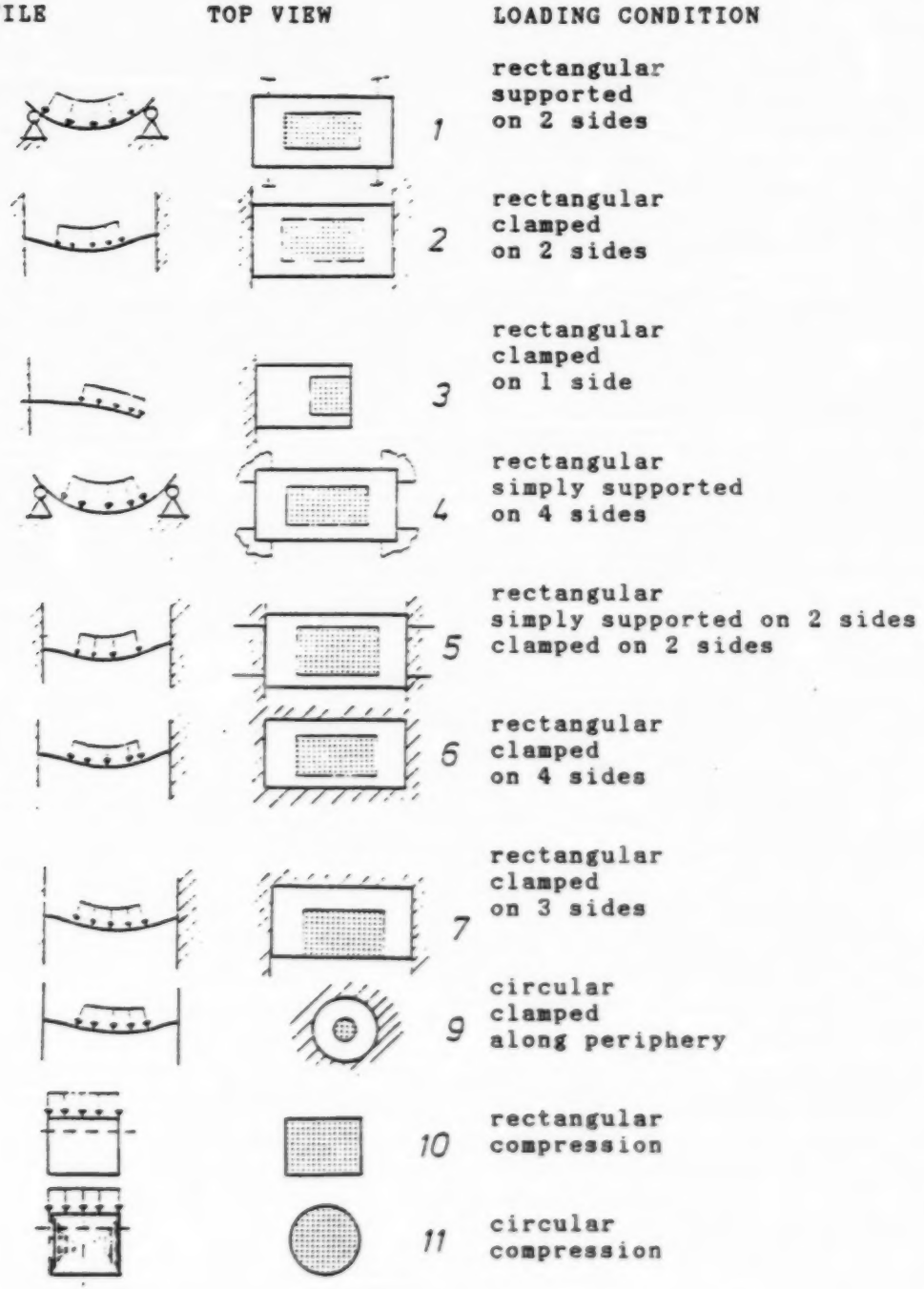


FIGURE 37: Summary of element types and loading conditions

- Deformation type i.e. bending due to shearing, compression, ...
- Shape of the mould element i.e. rectangular, circular, ...
- Boundary conditions i.e. number of the free, simply supported or clamped sides

Fig. 37 shows the different loading conditions for various elements of that can combined into a complete mould system and the chapters that treat each loading condition.

The mechanical design program has the following capabilities:

1. Calculation of the deformation of single mould elements, at various locations in the mould, from the element geometry, mould material and loading level.
2. Calculation of a specific dimension (e.g. plate thickness) of a given mould element, from the mould geometry, mould material, loading level and maximum desired deformation.
3. Calculation of the total deformation of the entire mould system from the superposition of the deformations of various single elements.
4. Calculation of the resulting deformation of a particular mould element from a desired total deformation of the entire mould system.

5.2 SUPERPOSITION OF TWO BOLTED OR STACKED PLATES

5.2.1 Superposition Procedures

A mould often consists of several standard parts or elements, such as floating plates or screwed plates.

When the plates are screwed together tightly (Fig. 38), the total thickness (equal to the sum of the individual plates' thicknesses) can be used for deformation calculations.

If the plates are not screwed together tightly, i.e. floating plates, they must be superposed appropriately for the deformation calculation, using the following procedure:

a) Creation of the equivalent spring system, where each element has an equivalent spring
b) Numbering the planes in the equivalent spring system
c) Issuing codes to the elements or equivalent springs
d) Description of the loading conditions and the geometry for each element
e) Calculation of the total deformation of the system

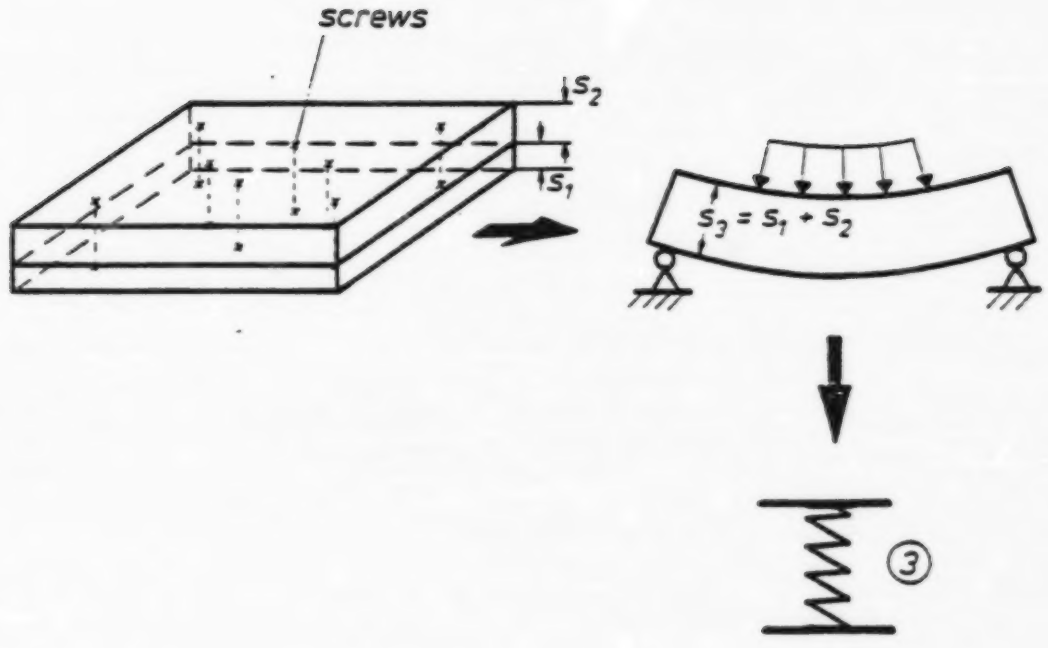


FIGURE 38: Deformation of two plates tightly screwed together

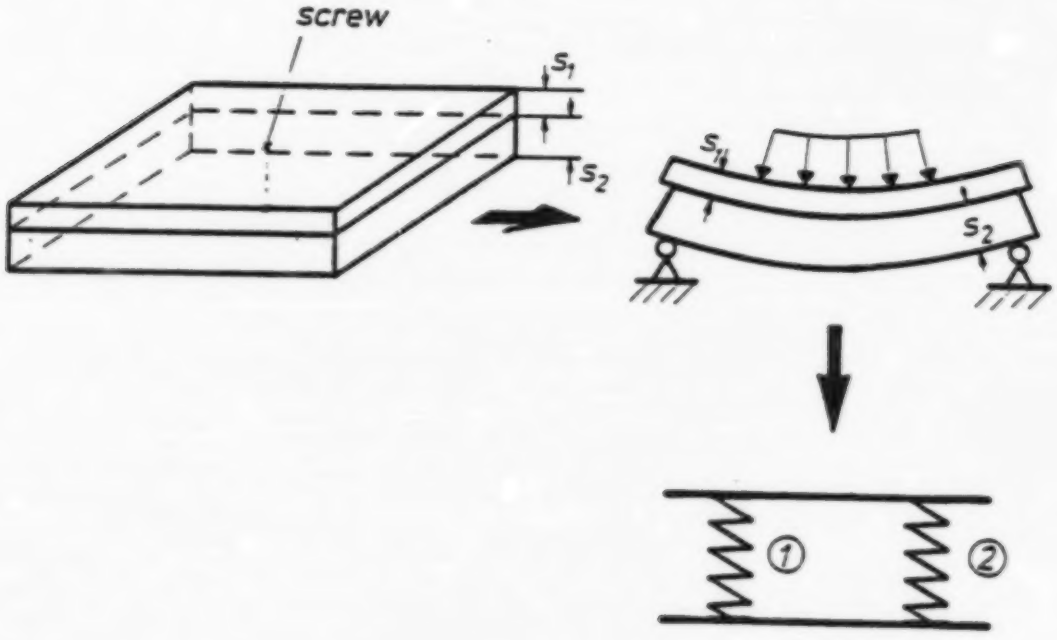


FIGURE 39: Deformation of a floating plate assembly

f) Calculation of the deformation of a single element with a predetermined total deformation of the system
g) Dimensioning a single element with a predetermined deformation

This procedure will be applied to the floating plate assembly described by Fig. 39 .

5.2.2 Creation Of The Equivalent Spring System

The equivalent spring system is based on how the various elements relate to each other. There are two types of connections between the springs that each represent an element.

a) Parallel Connection
- the deformations of the elements or springs are equal; the total deformation is equal to any of the individual deformations
- the elements reinforce each other

b) Series Connection
- the deformations of the elements or springs add up to the total deformation
- the elements do not reinforce each other

For floating plates, which reinforce each other, both elements are equally deformed and are thus connected in parallel.

5.2.3 Numbering The Planes In The Equivalent Spring System

The planes in an equivalent spring system are located between the springs. They are numbered consecutively. See fig. 40 a)

5.2.4 Issuing Codes To The Elements Or Equivalent Springs

The element or equivalent spring codes (or numbers) consist of three digits. Each digit has the following significance.

DIGIT	SIGNIFICANCE	LIMITS
1st	plane from which the spring is "coming"	1 to 8
2nd	plane to which the spring is "going"	2 to 9
3rd	when more than one spring lies between two planes, this digit provides identification	1 to 9

The planes must be numbered successively, from top to bottom or bottom to top; the direction makes no difference. The elements between two planes must numbered in sequence.

The use of a three digit code limits the complexity of the system to nine planes and nine springs between each plane.

The element coding clearly defines the structure of the equivalent spring system.

1. Elements with codes whose first digits are the same are connected in parallel (e.g. 133 and 134)

2. If the 2nd digit of one element code equals the 1st digit of another element code, then these elements are connected in series (e.g. 131 and 341)

An example follows.

ELEMENT	LOCATION	CODE
No. 1	from plane 1	1
code	to plane 2	1 2
121	spring no. 1	1 2 1
No. 2	from plane 1	1
code	to plane 2	1 2
122	spring no. 2	1 2 2

This results in the codes of figure 40 b):

5.2.5 Description Of The Loading Conditions And The Geometry For Each Element

For each element, the loading conditions and the geometry must be defined. For example:

ELEMENT 121:
- Loading conditions:
  - rectangular plate
  - loaded in shear and bending
  - simply supported on two sides
- Geometry:
  - length
  - width
  - height

ELEMENT 122:
- Loading conditions:
  - same as ELEMENT 121
- Geometry:
  - length
  - width
  - height

As well, the applied load and its position must be specified.

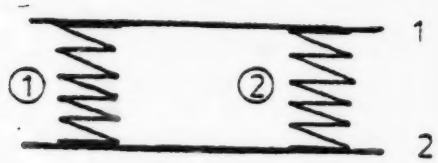


FIGURE 40: Numbering of planes : a)

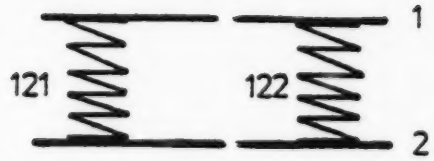
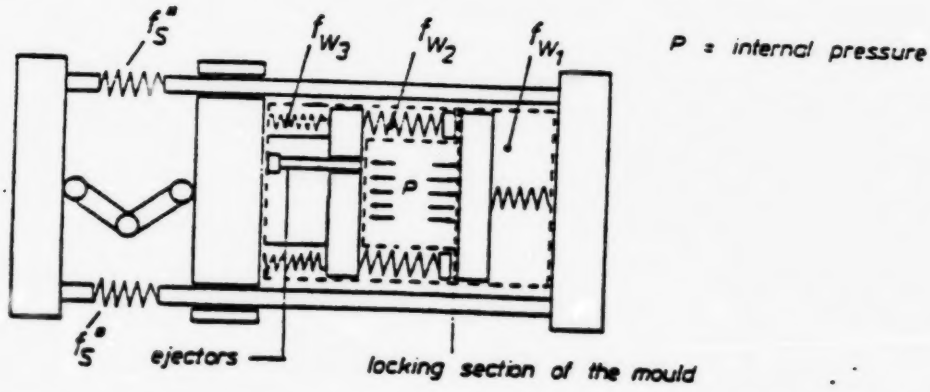


FIGURE 40: Numbering of planes : b)

5.2.6 Calculation Of The Total Deformation Of The System

The program first determines the deformations of the individual elements. These deformations are then successively superposed, starting with the elements connected in parallel, followed by the elements connected in series. This procedure continues until the equivalent spring system is reduced to one single element from which the total deformation is calculated.



Simplified diagram of a clamping unit and a mold with the equivalent spring system